Highlights of MCBXF Activities at Elytt Energy

O.Durán, C. Martins, **F. Toral** (CIEMAT)
J. C. Pérez (CERN)

12th HL-LHC Coll. Meeting – 21th Sept. 2022

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- MCBXF series contract
- Production of components
- First short magnet assembly MCBXFB02
- Quality assurance
- Conclusions

Let’s start with a reflection…

- The **key question** is: Should a magnet prototype be developed in house or in industry?
- In the case of MCBXF magnets, I have no doubt:
  - **Short experience** on nested magnets in the community
  - Some **novel problems** to overcome:
    - Hard radiation resistance requirement for a nested superconducting magnet
    - Coil wound with a high number of Rutherford-cable turns
  - Some **surprises**:
    - Cables at coil heads are not laying down
    - Internal stresses in slim 3D-printed stainless steel spacers
    - Tolerances in large fine-blanked collars
  - An **enemy** more dangerous than initially expected: torque at coil heads

Let’s conclude from the reflection…

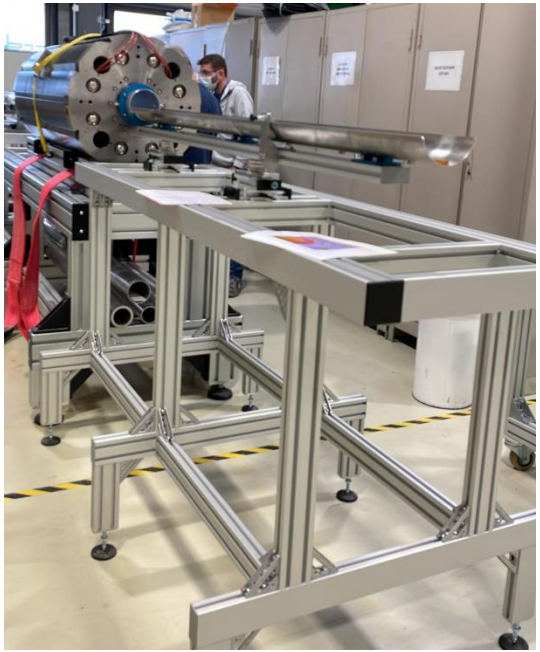
- Series contract strategy is based on **accumulated experience**:
  - Clear mitigation of risks
  - Shorter learning curve
  - Precise definition of manufacturing procedures
  - Easier choice of quality assurance methods
- **Last but not least**:
  - Overall cost is lower
  - Long lead times of some components is overcome with stocked ones
  - The traveling distance to the company is time-consuming and follow-up cannot be so close

MCBXF series contract

- Contract signed with **Elytt Energy** at **March 2021**: delivery of 6 long (A) and 11 short (B) MCBXF magnets.
- All **documents** and **templates** (technical specification, acceptance criteria, manufacturing and inspection plan, quality documentation…) have been agreed with CERN.
- CIEMAT has prepared detailed **procedures** for each step of production: coil winding, binder, impregnation, assembly, parts production (ground insulation, collar packages, collaring shoes). They are uploaded to EDMS. There are thousands of photos to help **know-how transfer**.
- **CIEMAT staff** has been at Elytt premises during six months for know-how transfer on coil production. Daily support for production follow-up, questions and incident solving. **CIEMAT and CERN staff** has supported the first magnet assembly at Elytt.
- CIEMAT is supporting Elytt to contact **suppliers** for components, tooling and materials.

MCBXF series contract: parts exchange

- CIEMAT is supplying the copper wedges, the end spacers and the collars (fine blanked). It means an important effort for quality assurance.
- CERN is supplying the insulated superconducting cable, the steel for the collars, the iron for the yokes, the keys for the outer dipole collars and the instrumentation of the collars.
- CERN has supplied the warm magnetic measurement bench and training.
  - CERN has trained a CIEMAT colleague during three months.
- CERN will take care of powering tests (at SM18 or FREIA).
- CIEMAT and CERN are supplying some components for series production that are not arriving at Elytt in time.



Magnetic measurement bench (Courtesy J. C. Pérez)

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MCBXF series: Elytt Energy facilities

- Two closed **clean rooms** with controlled humidity and temperature:
  - **Coil production**: two lines (winding machine + binder mould + impregnation), component preparation (preforming ground insulation and collaring shoes, collar package assembly, collared coil assembly).
  - **Magnet assembly**: collaring press, yoke assembly, magnetic and final electrical measurements.

Hall with two clean areas: coils (left) and magnets (right)

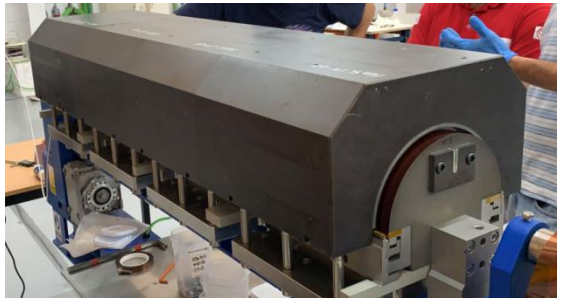
Coil production area

Magnet assembly area

Courtesy: Elytt Energy

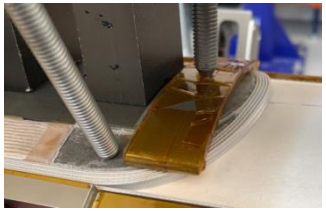
MCBXF series: coil production at Elytt

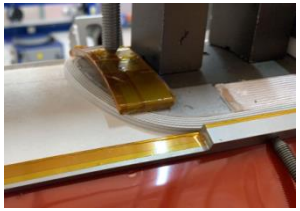
IL Winding



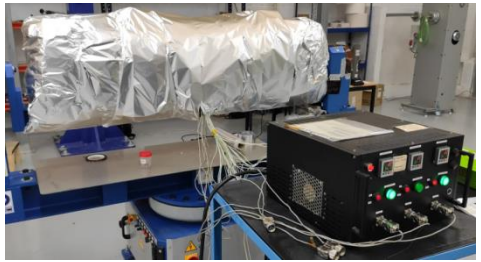
IL Binding

Impregnation mould assembly



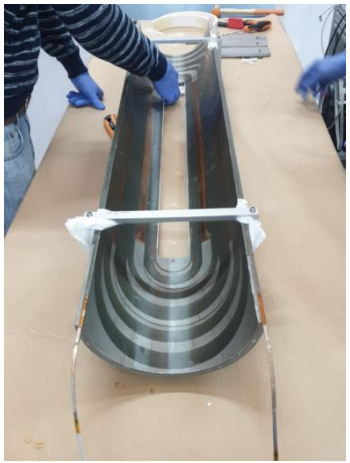


OL Winding



OL Binding

Courtesy: M. Oñate (Elytt Energy)



First finished coil

MCBXF series: coil production

- Delicate production process with a **long learning curve**: in-site support with detailed procedures.
- Three inner coils and one outer coil are in quarantine because of **faulty impregnation**.
- Two inner coils were used for reassembly of second prototype (MCBXFBP2c) to **validate** the production techniques.
- Only B-type coils up to now. **A-type coil** production is being set-up.

Courtesy: Elytt Energy

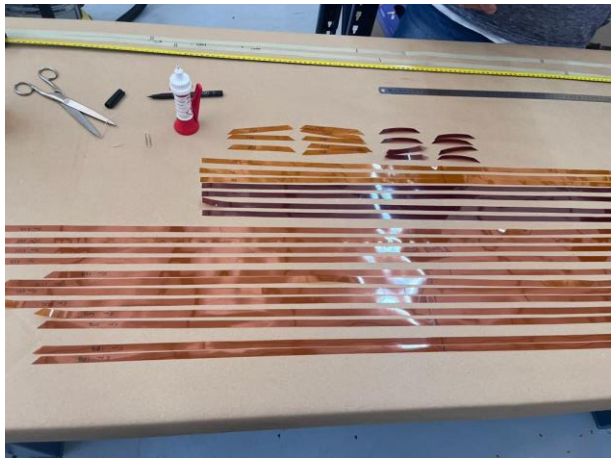
Coil winding

Binder curing

Impregnation mould assembly

MCBXF series magnets: other components

- Elytt is following **CIEMAT procedures** to produce ground insulation, collaring shoes and collar packages.
- **CIEMAT** provides **support** to find suppliers for other magnet components, like the iron laminations.



Shimming plan for inner dipole

Collar packages for inner dipole

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MCBXF series magnets: first magnet assembly

- CERN and CIEMAT have provided in-site support for the assembly of the first magnet last Summer.

Inner dipole ready for collaring press

Inner dipole entering the collaring press

MCBXF series magnets: final measurements

- CERN and CIEMAT have provided support for electrical, mechanical and magnetic measurements.

Electrical measurements

Magnetic measurement bench

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MCBXF series: quality assurance

- **Quality controls** of each step of production are defined in the manufacturing and inspection plan (MIP), both for coils and magnets.
- **A third-party inspector** will follow-up production till the end of the contract.

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas — HiLumi HL-LHC PROJECT

EDMS NO.	REV.	VALIDITY
2335157	0.0	DRAFT

REFERENCE: LHC-MCBXFB-FP-0001

HL-LHC: Quality
Manufacturing and Inspection Plan – MCBXFB Coil

Prepared by: R. Diaz Vez, J.C. Perez (CERN) **Date:** 24/02/2020	**Project:** HL-LHC	**Executing Entity:** TBC **Supplier:** CIEMAT	**Item Eq. Code:** HCMCBXFBC002 HCMCBXFBC006	**Asset Code (LHC Part Identifier):** **HCMCBXFBC002-E90000 _ _** **HCMCBXFBC006-E90000 _ _**
Verified by: _____ **Date:** _____				
Approved by: _____ **Date:** _____	**Work Package:** WP03	**Client:** CERN (HL-LHC WP03)	**Item description:** MCBXFB OUTER COIL OCBS11 (HCMCBXFBC073-E5000009)	**EDMS Report No:**

No	ACTIVITY / OPÉRATION	APPL. STANDARDS / NORMES APPL.	APPLICABLE DOCUMENTS / DOCUMENTS APPLICABLES	REV. DOC.	INSPECTION / CONTRÔLE								NOTES / COMMENTAIRES / REPORTS
					EXECUTING ENTITY		SUPPLIER		CLIENT		3RD PARTY / SURVEILLANCE		
					Code	Signature/Date	Code	Signature/Date	Code	Signature/Date	Code	Signature/Date	
A	**PRODUCTION START-UP**												
A.1	Magnet Procedures version verification		All Magnet procedures		IN	15-06-2022							Check if all applicable procedures are in the last version available
A.2	Production start-up				IH	15-06-2022	H	28-06-2022	N				Notification by email

MIP for coil production

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EDMS NO.	REV.	VALIDITY
2335158	0.0	DRAFT

REFERENCE: LHC-MCBXFB-FP-0002

HL-LHC: Quality
Manufacturing and Inspection Plan – MCBXFB Magnet

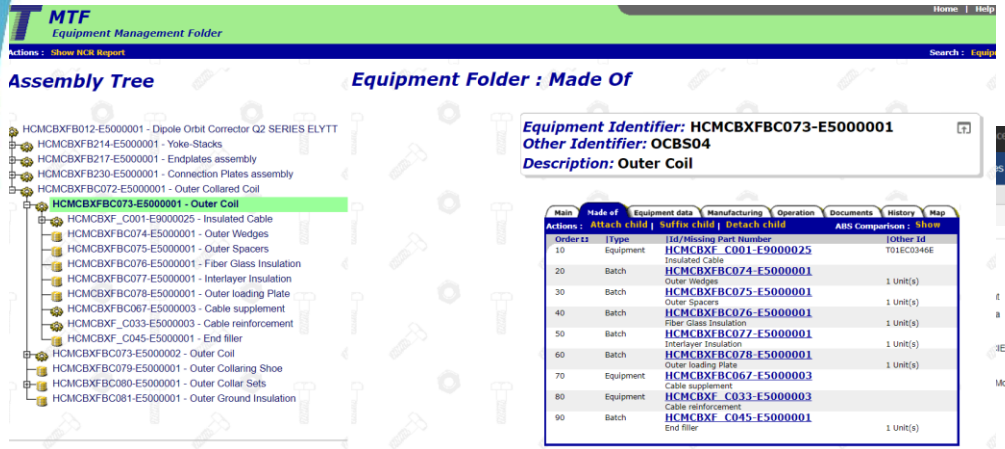
Prepared by: R. Diaz Vez, J.C. Perez (CERN) **Date:** 24/02/2020	**Project:** HL-LHC	**Executing Entity:** TBC **Supplier:** CIEMAT	**Item Eq. Code:** HCMCBXFB001	**Asset Code (LHC Part Identifier):** **HCMCBXFB001-E90000 _ _**
Verified by: _____ **Date:** _____				
Approved by: _____ **Date:** _____	**Work Package:** WP03	**Client:** CERN (HL-LHC WP03)	**Item description:** MCBXFB MAGNET	**EDMS Report No:**

No	ACTIVITY / OPÉRATION	APPL. STANDARDS / NORMES APPL.	APPLICABLE DOCUMENTS / DOCUMENTS APPLICABLES	REV. DOC.	INSPECTION / CONTRÔLE								NOTES / COMMENTAIRES / REPORTS
					EXECUTING ENTITY		SUPPLIER		CLIENT		3RD PARTY / SURVEILLANCE		
					Code	Signature/Date	Code	Signature/Date	Code	Signature/Date	Code	Signature/Date	
A	**INNER COLLARING COMPONENTS**												
A.1	Acceptance of Inner Collaring components				N		N						Upload to EDMS all Traceability & dimensional reports (components)
A.2	Inner Coils Acceptance				IH								Inner Coils Acceptance Documents
B	**INNER COLLARED COIL**												
B.1	Shimming plan for Inner collared coils		Inner Dipole Assembly procedure		N		H		H				Upload to EDMS the *Shimming Plan Report*
B.2	Inner Collared Coils, Electrical test (before collaring)		Electrical Test procedure		N		N						Upload to EDMS the *Electrical Test Report*

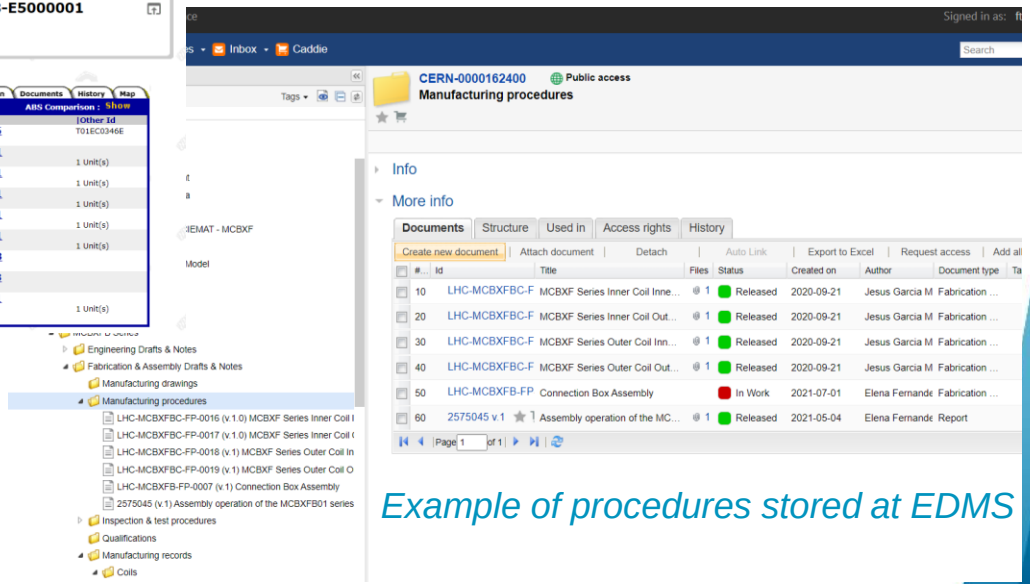
MIP for magnet assembly

MCBXF series: documentation

- **Traceability** is guaranteed thanks to documentation stored in **MTF**.
- Drawings, minutes, measurements and other documents are stored in **EDMS**.



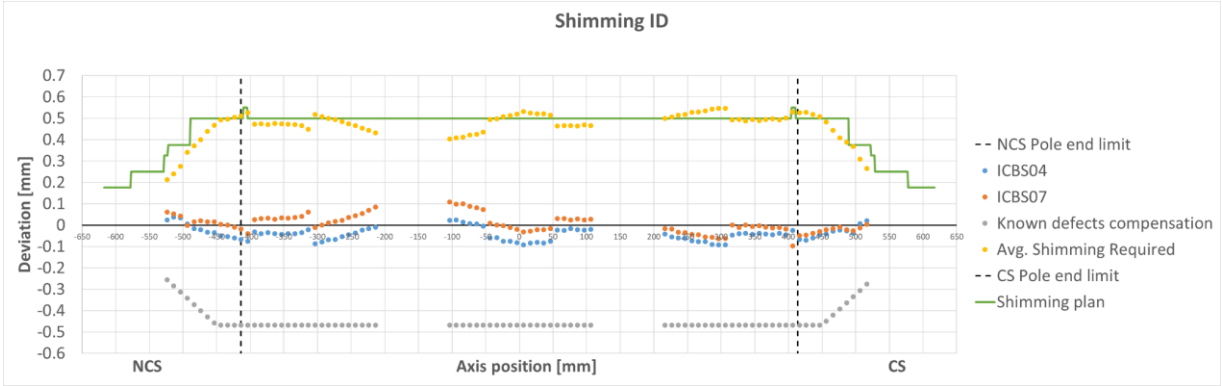
Example of coil data stored at MTF



Example of procedures stored at EDMS

MCBXF series: coil dimension measurements

- Coil dimension is measured with accuracy in a **coordinate measurement machine**.
- The coil is **clamped** to the winding mandrel to reduce the deformation due to internal stresses in free state.
- Those measurements are used to define the **shimming plan** (0.1 mm shim -> 15 MPa preload).



Outer coil at CMM

MCBXF series: electrical measurements (I)

- Electrical design criteria are defined in **EDMS 2363905**.

Maximum expected coil-to-ground voltage at quench (V)	$V_{sim\ (ground)}$
Test voltage at NOC at *'Manufacturing Facilities and Test Stations'* stage (V)	$V_{test1\ (ground)} = 2 * V_{sim\ (ground)} + 500$
Test voltage at warm[(1)] before first helium bath (V)	$V_{test2\ (ground)} = 2 * V_{test1\ (ground)}$
Test voltage at warm[(1)] after helium bath (V)	$V_{test3\ (ground)} = V_{test1\ (ground)} / 5$
Test voltage at NOC at *'Tunnel'* stage (V)	$V_{test4\ (ground)} = 1.2 * V_{sim\ (ground)}$

(1) T = 20±3 °C and humidity lower than 60%

Table 2. Maximum voltages to ground for MCBXFA/B corrector magnets with energy extraction resistance of 0.15 Ω.

Magnet		Nominal current (A)	Maximum voltage to ground (V)
MCBXFA	Inner Dipole (ID)	1584 A	238
	Outer Dipole (OD)	1402 A	210
MCBXFB	Inner Dipole (ID)	1625 A	244
	Outer Dipole (OD)	1474 A	221

MCBXF series: electrical measurements (II)

Table 3. Nested orbit correctors electrical test values at *'Manufacturing Facilities and Test Stations'* stage.

Test name	Test voltage	Value
Test voltage at NOC at *'Manufacturing Facilities and Test Stations' stage* (V)	$V_{test1\ (ground)}$	1000
Test voltage at warm[(1)] before first helium bath (V)	$V_{test2\ (ground)}$	2000
Test voltage at warm[(1)] after helium bath (V)	$V_{test3\ (ground)}$	200
Maximum leakage current (μA) – not including leakage of the test station		10
Test voltage duration (s)		30

Table 4. Nested orbit correctors electrical test values at *'Tunnel'* stage.

Test name	Test voltage	Value
Test voltage at NOC at *'Tunnel' stage* (V)	$V_{test4\ (ground)}$	300
Test voltage at warm[(1)] after helium bath (V)	$V_{test3\ (ground)}$	200
Maximum leakage current (μA)		10
Test voltage duration (s)		30

MCBXF series: magnetic measurements

- Magnetic measurement **bench** developed by CERN.
- CIEMAT staff has been **trained** at CERN to handle the bench and post-process the measurements.
- CIEMAT staff is **supporting** the first measurements at Elytt and training them to use the bench.

Conclusions

- The series magnets are in production at **Elytt Energy**.
- **CIEMAT and CERN** have provided **support** to set up the production: in-site help, procedures and know-how transfer.
- The **first two valid inner dipole coils** have been assembled into **MCBXFBP2c** magnet, which has been successfully tested. It validates the coil production process at the company.
- The **first short magnet** is being shipped to CERN today.
- **A-type** coil production is being set-up.

Acknowledgements to:

Manuel Domínguez, Óscar Durán, Jesus Angel García Matos, Luis González, Jesús Jiménez, Carla Martins, José Antonio Pardo, Pablo Sobrino from **CIEMAT**
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