MCBXFB Short Orbit Corrector Prototype: Status update

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WP3 Meeting – 11th October 2017

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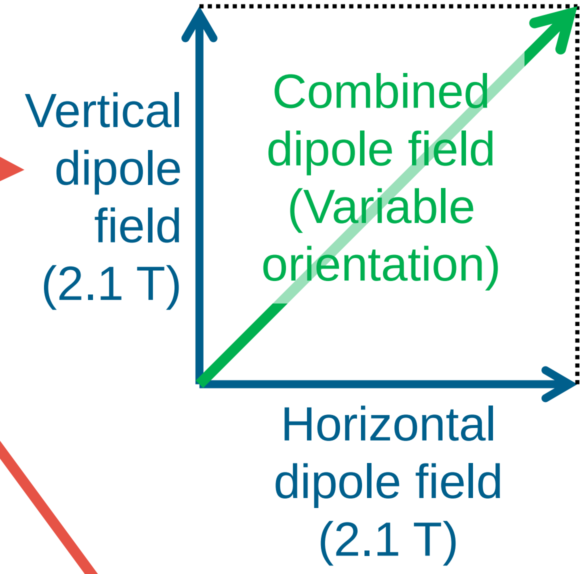
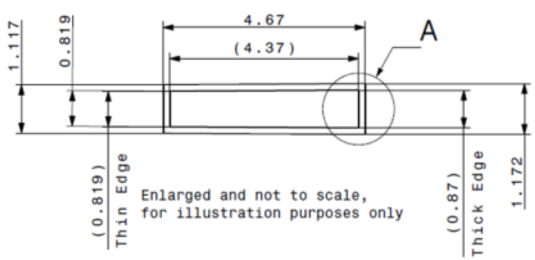
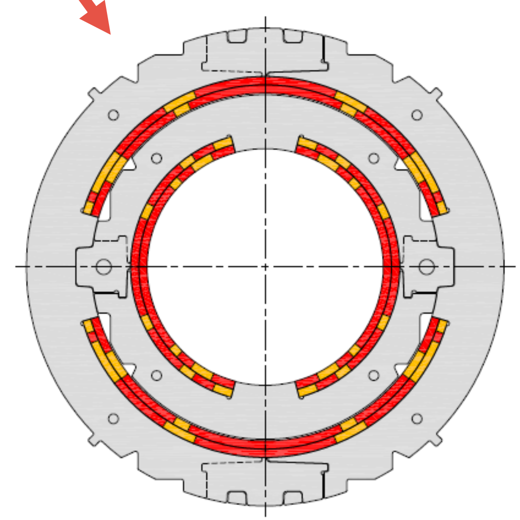
Magnet and cable specifications

MCBXFB Technical specifications	
Magnet configuration	Combined dipole (Operation in X-Y square)
Integrated field	2.5 Tm
Minimum free aperture	150 mm
Nominal current	< 2500 A
Radiation resistance	40 MGy
Physical length	< 1.505 m
Working temperature	1.9 K
Iron geometry	MQXF iron holes
Field quality	< 10 units (1E-4)
Fringe field	< 40 mT (Out of the Cryostat)



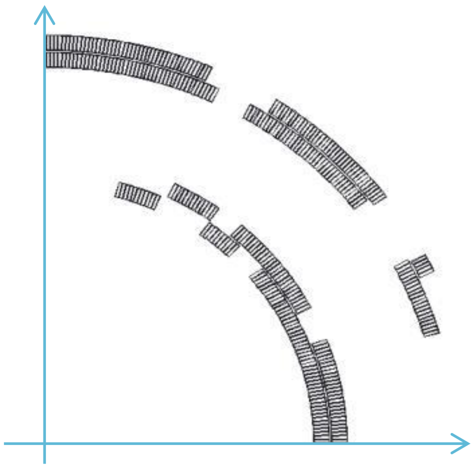
Cable Parameters	
No. of strands	18
Strand diameter	0.48 mm
Cable thickness	0.845 mm
Cable width	4.37 mm
Key-stone angle	0.67º
Cu:Sc	1.75

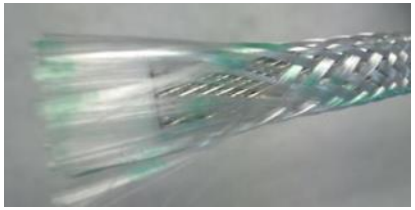




Manufacturing concept and coil fabrication remarks (I)

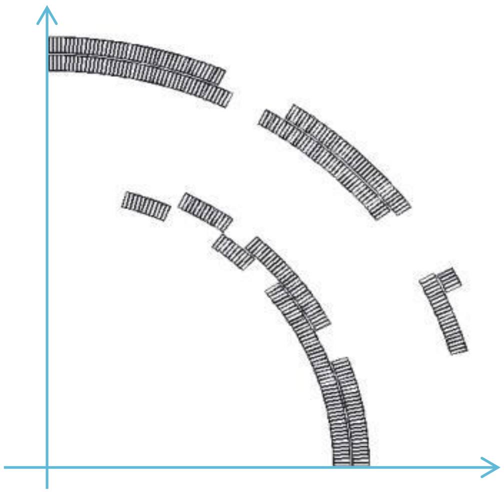
- Double pancake coils of small NbTi cable with large aperture lead to **large number of turns**:
  - Unpredictable cable lay down at coil ends.
  - Large number of wedges and endspacers are necessary.
- Traditional coils made with polyimide insulated cables would be too spongy: dimension control would be very challenging. **Fully impregnated coils** would ease the dimension accuracy.
- **Resin** should be radiation hard and have a good mechanical behaviour. CTD 422 resin was validated, but finally it was decided to switch to CTD 101K instead, due to some doubts about the mechanical resilience of 422.
- Cable should be insulated with **glass-fibre** to ease the impregnation.

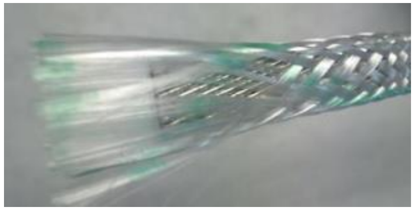




Manufacturing concept and coil fabrication remarks (II)

- The use of **binder** is necessary to hold the first layer while winding the second one. This binder must be compatible with the resin.
- Numerous tests using CTD **binder 1.1** have been carried out on small samples, but there is no previous experience on real coils.
- **Coil pre-stress** will be provided by self-supported stainless steel collars.
- **Iron yoke** will be laminated and will not provide additional mechanical support.
- MCBXF are **2-in-1 magnets**, given the inner/outer dipole configuration, so tooling is thought to be used in both magnets if possible, in order to reduce production costs.

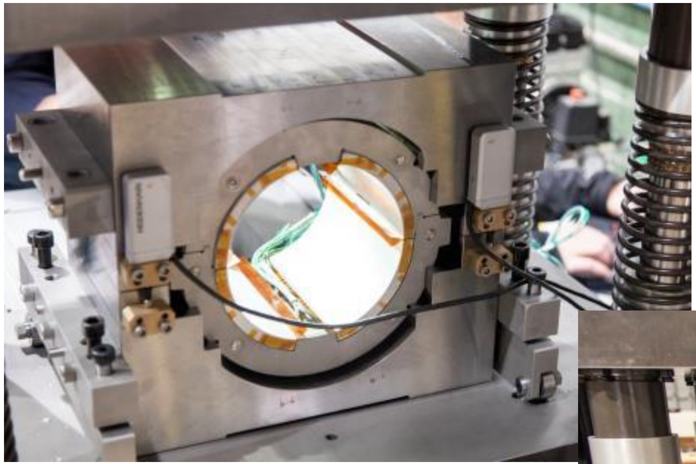


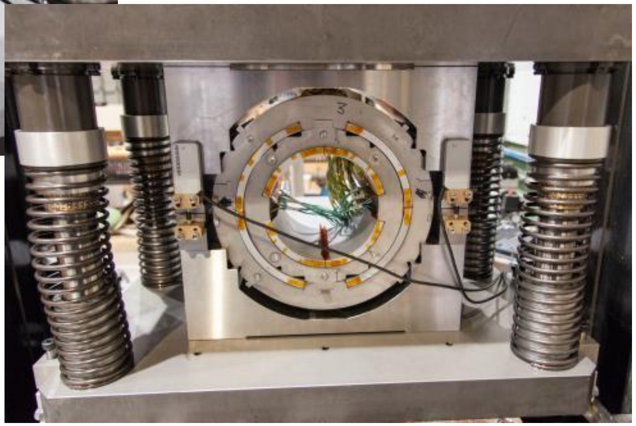


Last WP3 meeting reminder

- Successful short mechanical model test:
  - Measured and calculated values were very close.
  - Assembly procedure was easy to be followed. Some concerns for a full length coil.
  - In summary, the nested collar configuration is validated but some further tests are still necessary.

- **Test will be repeated with the right outer collar geometry and 180 deg dummy coils**
- **Cold tests will be carried out with Liquid N_2**





Next goal:

Complete outer dipole test

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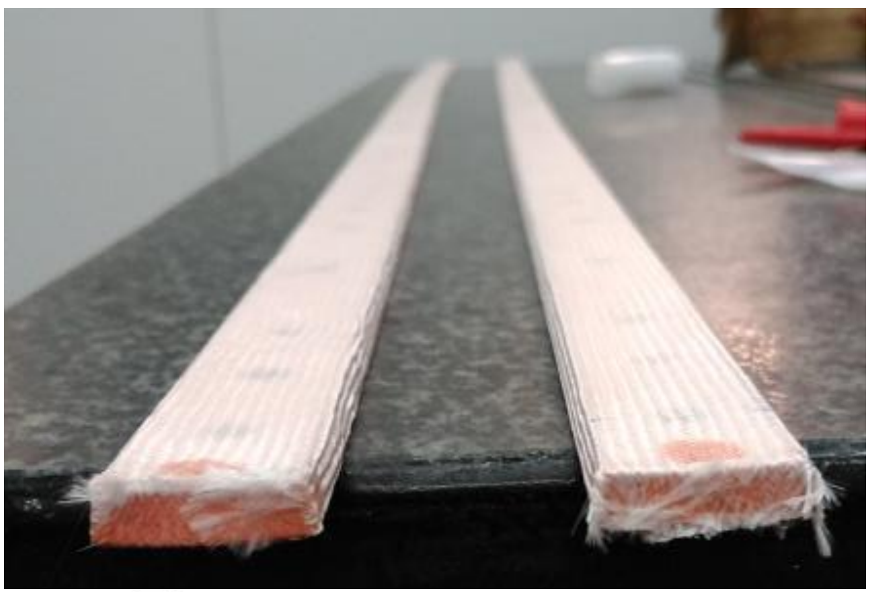
Coil Fabrication: Cable

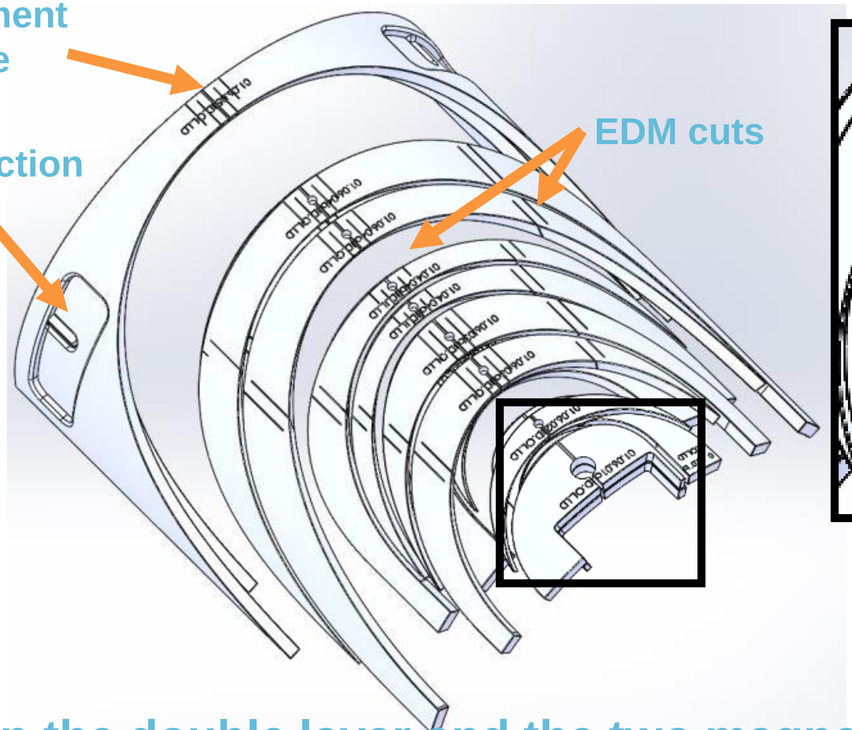
- The first full length spool was insulated with the **wrong type of glass-fiber sizing (636)**. It was noticed at the end of August, during the insulation of the next full length spool.
- Different tests have been performed at CERN&CGP. Finally, **66TEX933** fiberglass is woven around the cable, which is compatible with the resin and close to the nominal thickness of 135 micron (131 micron measured on ten-stack).
- We are grateful to **927 team** for their fast reaction and help.

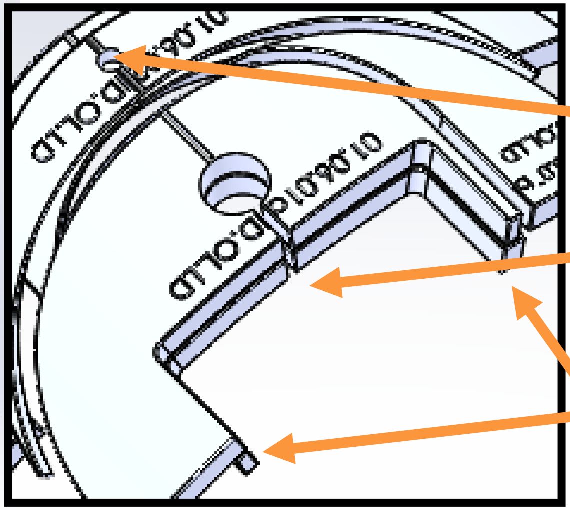
Coil Fabrication: Wedges

- **Each coil cross section needs 5 different wedges to provide a good field quality. They are produced by machining in parts of approximately 300 mm length. So each coil needs 30 parts.**
- **Insulation tests of full length wedge assemblies have been carried out using the minimum amount of cyanoacrylate possible, as binder was not a good solution to hold the insulating sleeves..**
- **Smaller sleeves will be soon available to minimize the need of cyanocrilate.**
- **Ancillary holes to hold the parts during machining will be filled with headless A4 stainless steel screws.**

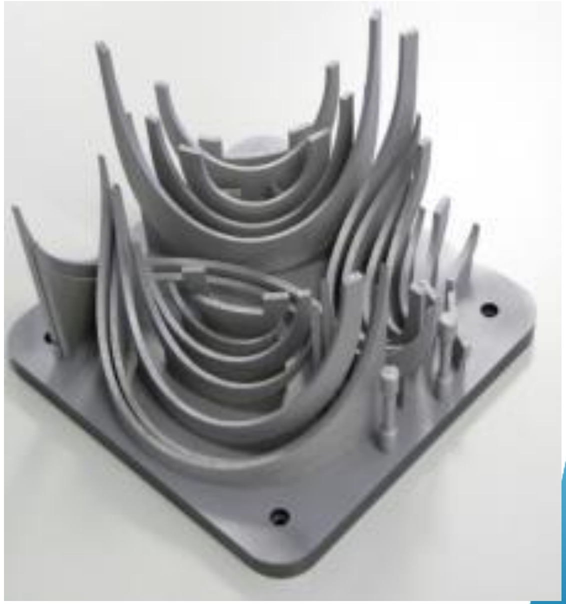


Coil Fabrication: End spacers





- Given the double layer and the two magnets necessary for the MCBXF, there are **58 different end spacers per magnet!!**
- Produced by 3D printing, several improvements and add-ons have been introduced after testing the first set.
- Large deformations (up to +/- 2 mm): EDM cuts are introduced.



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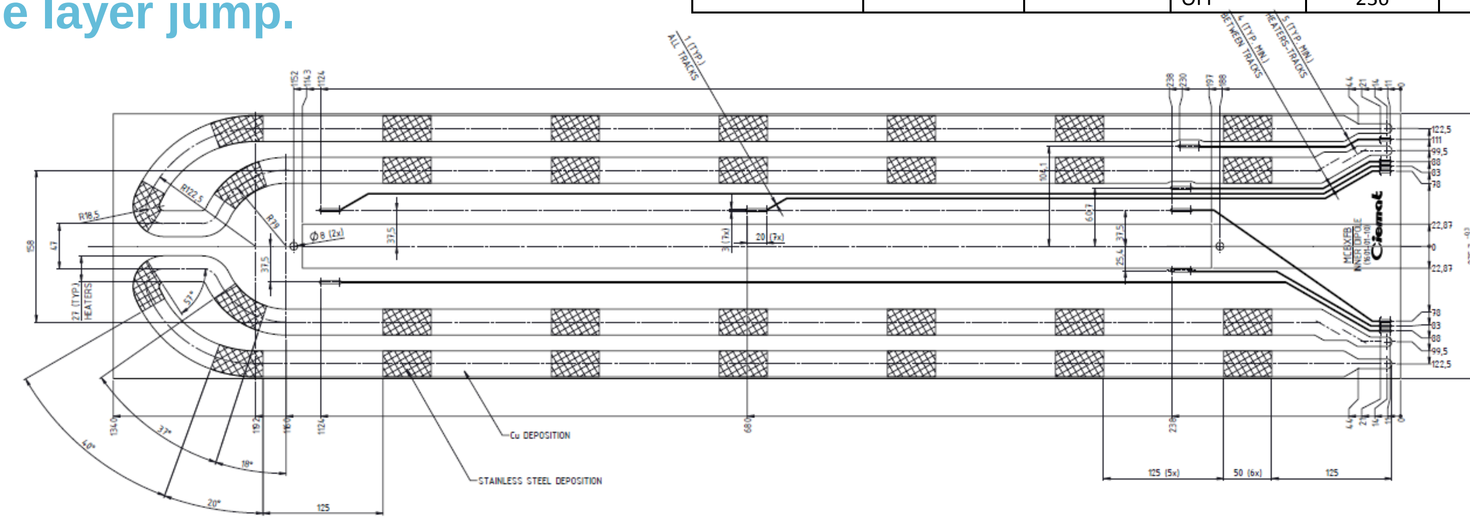
Coil Fabrication: Quench heaters

- Quench simulation with CIEMAT code **SQUID**, based on finite difference method.
- Heaters are necessary only for the long MCBXF, but will be implemented in the short prototype for **validation**.
- Heaters produced by **927** team.
- One **voltage tap** per cable block and at both sides of the layer jump.

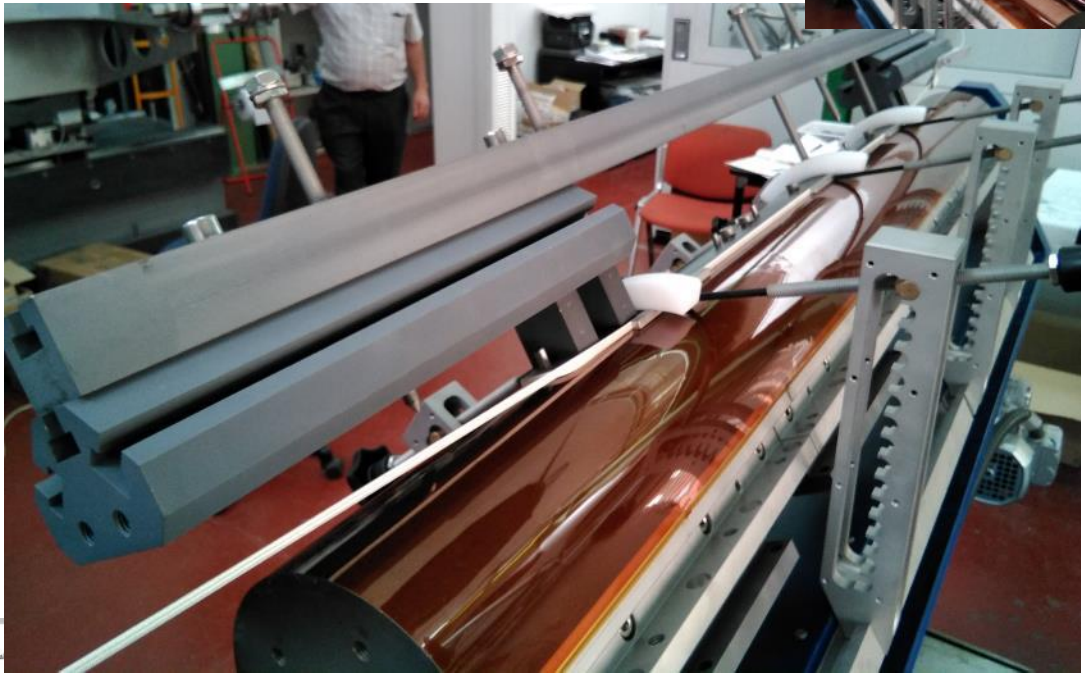
	Current	Dipole	Heaters	Tmax (K)	Vmax (V)
MCBXFA	Nominal	Inner	ON	126	393
			OFF	242	389
		Outer	ON	133	643
			OFF	284	618
	110 % nominal	Inner	ON	154	519
			OFF	274	504
		Outer	ON	160	847
			OFF	322	798
MCBXFB	Nominal	Inner	ON	129	234
			OFF	177	235
		Outer	ON	137	383
			OFF	211	376
	110 % nominal	Inner	ON	154	311
			OFF	198	308
		Outer	ON	163	504
			OFF	236	490



Coil Fabrication: Winding tooling

- Winding machine, pay-off and brake machines have been assembled, checked and calibrated.

- All winding tooling has been checked.



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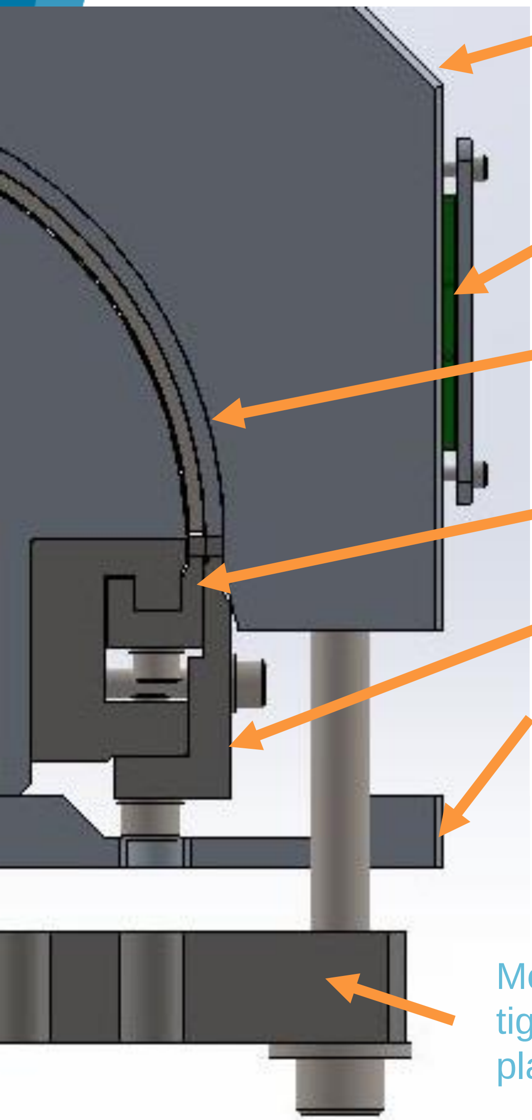
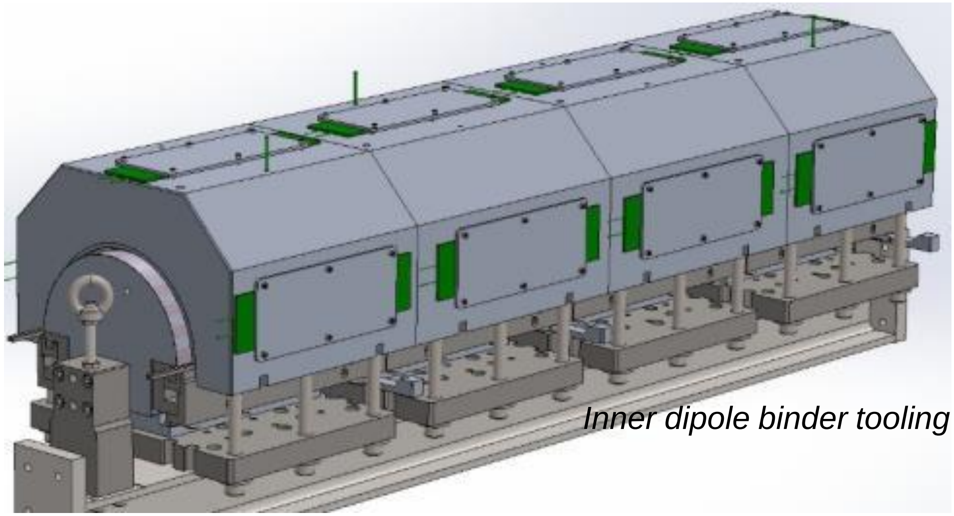
Coil Fabrication: Binder tooling (I)

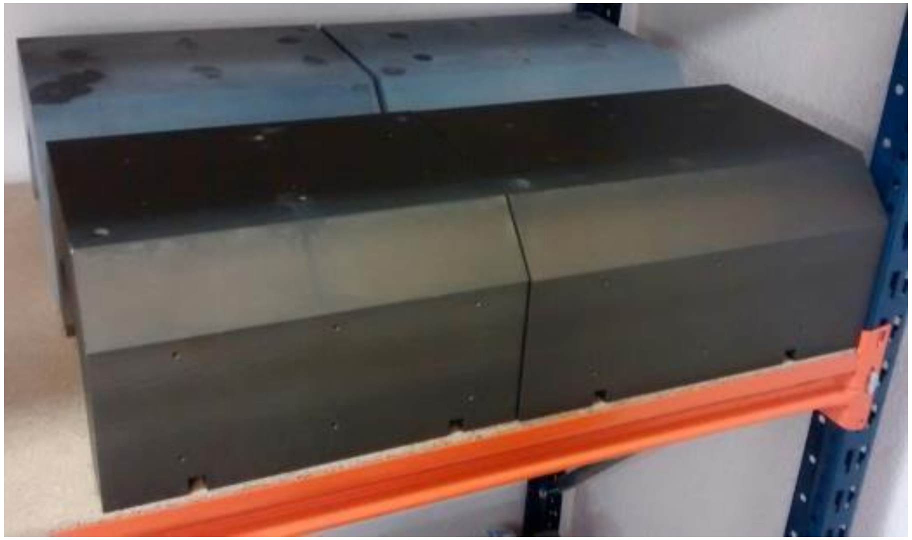


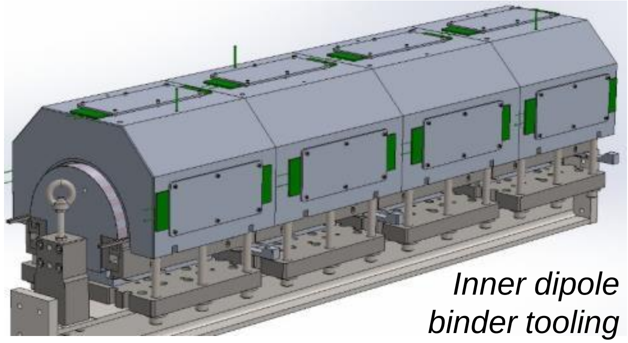
- **Last turns will drop below mid-plane during winding.**
- **It is necessary to apply the binder and take the cables to their position before applying heat (120 ºC, 12 h):**
  1. **Radial dimension is controlled by tightening the top tile of the mould.**
  2. **Cables are then pushed in place by the corresponding pusher.**
- **Mould is made of aluminium and stainless steel: careful design to avoid dangerous differential thermal elongations.**



Inner dipole binder tooling

Coil Fabrication: Binder tooling (II)

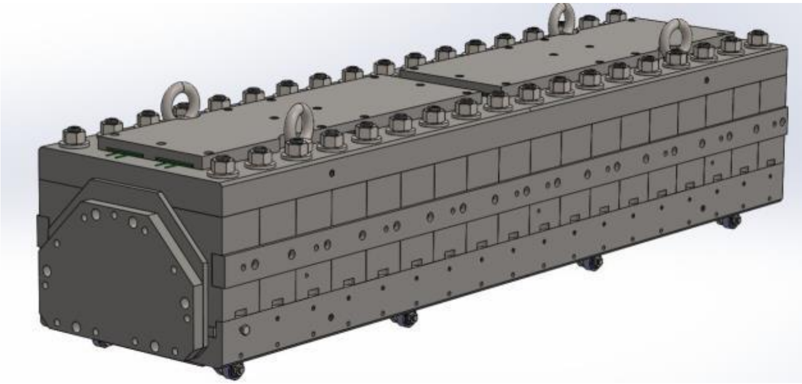


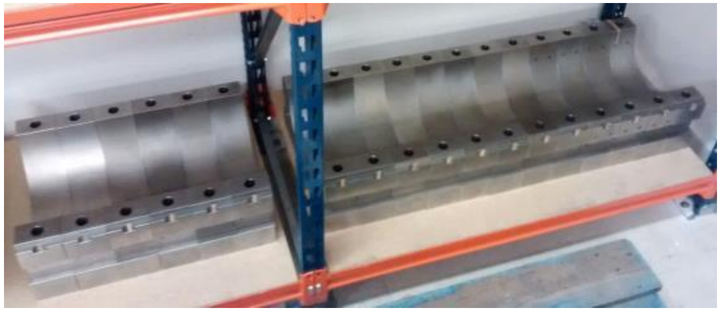


All parts are delivered and dimensionally checked

Coil Fabrication: Impregnation tooling

- **Impregnation assembly table ->**
  In production. Delivery at week 43.
- **Impregnation mould ->**
  Last parts will be delivered at week 43.
- **Vacuum Chamber ->**
  Assembled and ready.
- **Heating control system ->**
  It will be finished at week 42.





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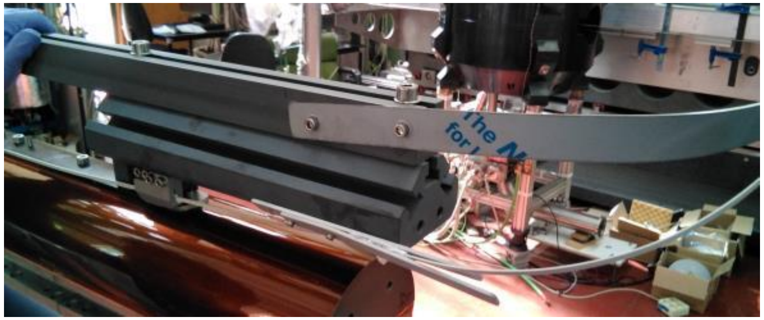
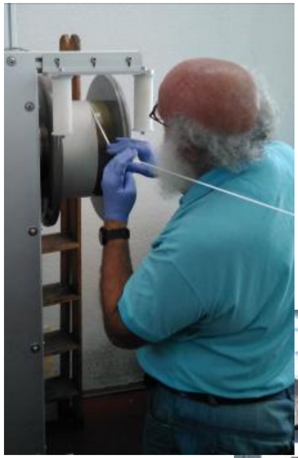
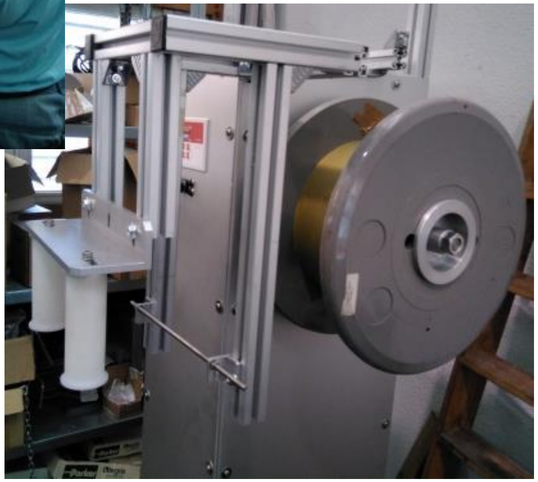
Winding & binding tests (I)

- **First winding and binding test** has been carried out.
- All **tooling** work as expected. Some minor modifications are ongoing for the first coil winding.
- The **pay-off machine** will be modified to allow regulating the height of the cable exit from the spool.
- **Tests** were carried out as follows with **60 m of cable**:
  1. Inner layer winding (15 turns).
  2. Inner layer binding using winding tooling (binder tooling can only be used for the complete coil).
  3. Interlayer positioning (Nomex).
  4. Outer layer winding (12 turns).
  5. Outer layer binding using winding tooling (binder tooling can only be used for the complete coil).

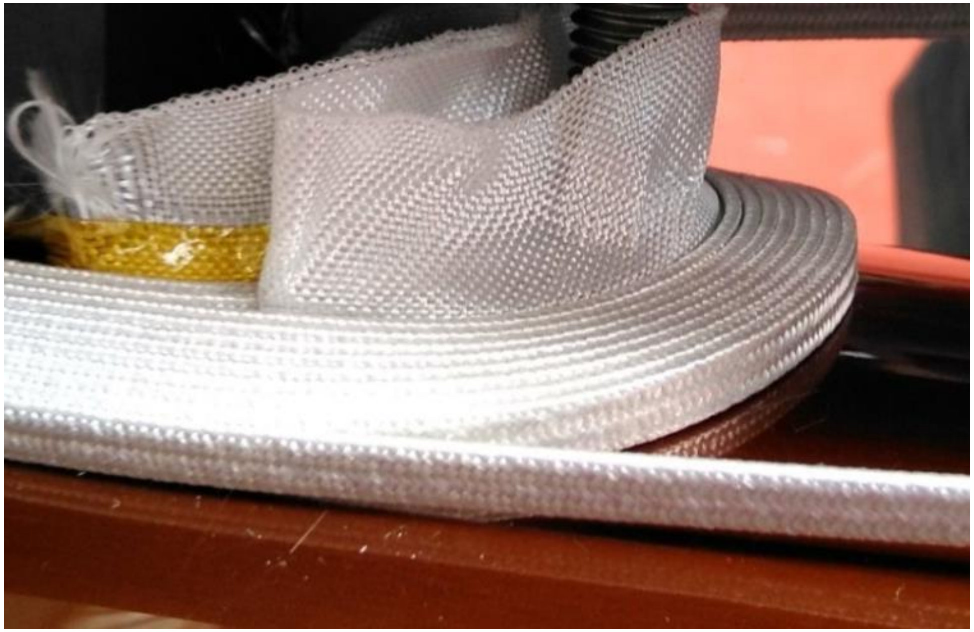


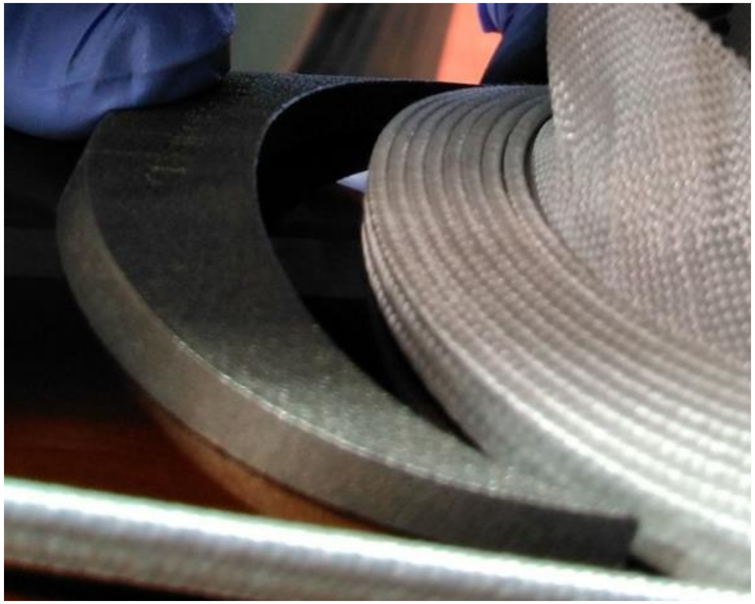




Winding & binding tests (II)

1. **Inner layer winding**
   - Main surprise is the behaviour of the **cables at coil ends**: they are not lying down as expected. Instead, they rest almost vertical at the mandrel symmetry plane.
   - Consequently, **endspacers** do not fit well but can be adapted by milling (manual). Longitudinal position is good within few tenths of mm.
   - First cable after an endspacer is jumping, even in the first turns. **Small arches** have been ordered to hold the cables in position.
   - **Winding tension** has been 5 kg at first turns, decreasing to 4 kgs after 10 turns.

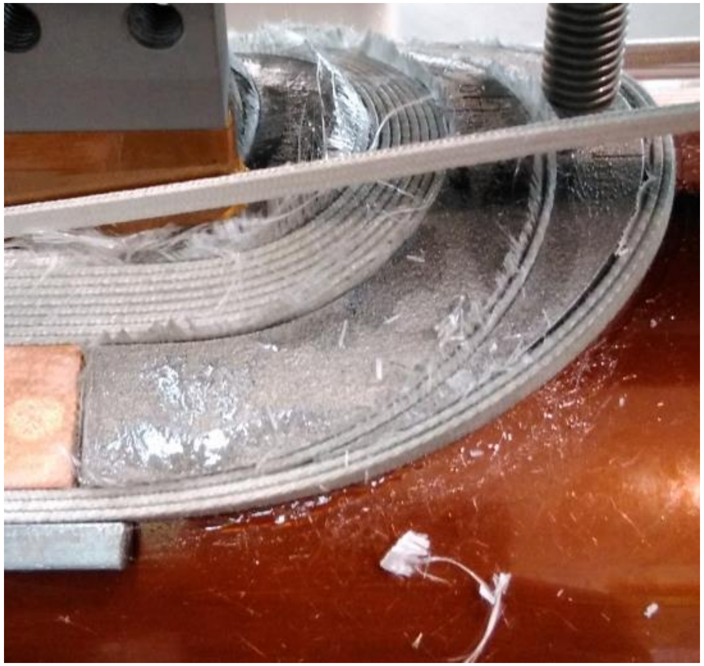


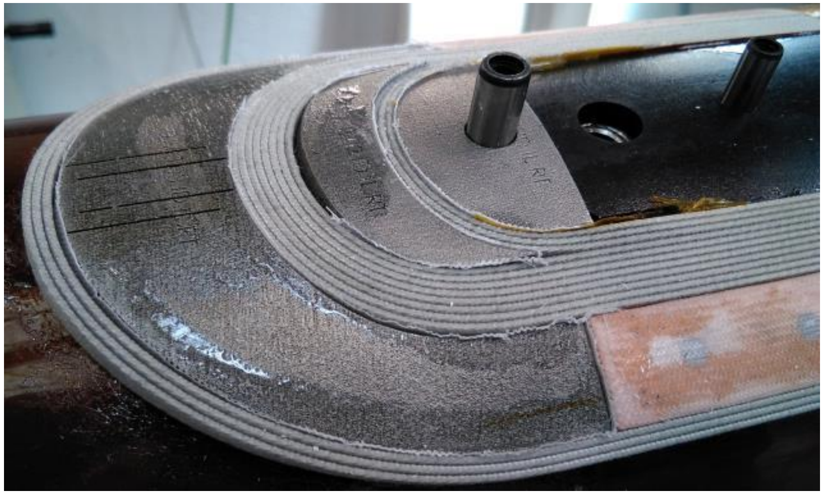


Winding & binding tests (III)

2. Inner layer binding

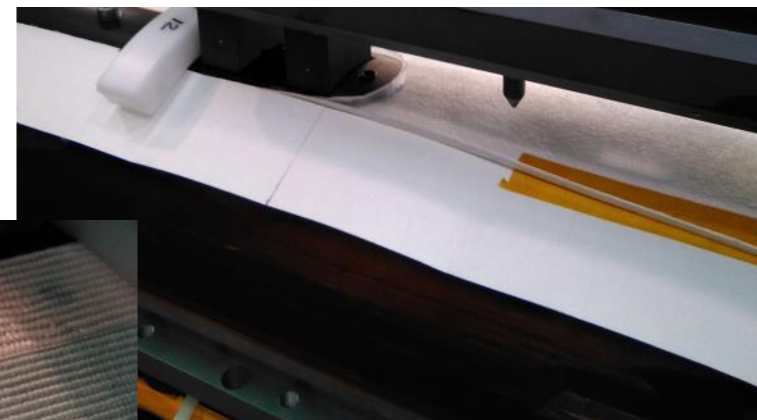
- A full length additional lateral pusher is added to the winding tooling for binder application.
- **0.6 g per cable meter** is applied, as in the ten-stack samples.
- The cables were heated up to 59ºC with a custom set-up during two days. The binding was not optimal, but it allowed to wind the outer layer. 120 ºC during 12 h will be used for the real coil.
- It was difficult to cut the glass-fibre tapes to the right height.

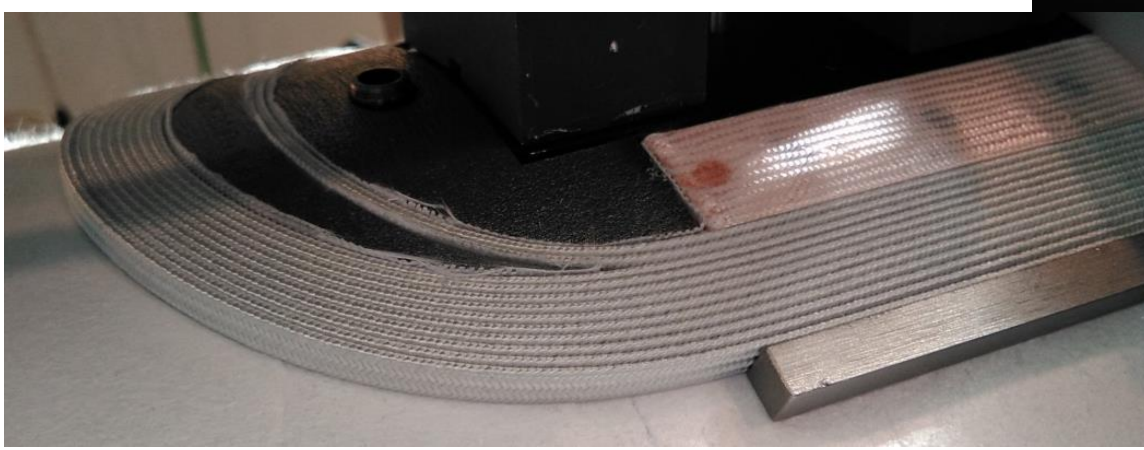




Winding & binding tests (IV)

3. **Interlayer**
   - It must not be cut for assembly. Cable slides smoothly.
4. **Outer layer winding**
   - Fiberglass tape for end spacer insulation is **pre-impregnated with binder** and cut to 5 mm height. It behaves much better this way: no sliding, good positioning and cleaner finish.
   - Cable behaviour at the coil ends as in the inner layer: it becomes almost vertical.
   - Voltage taps were not included. A test was made with a ten-stack sample.
5. **Outer layer binding**
   - Same procedure and setup as in the inner layer. Slightly higher temperature (63ºC).





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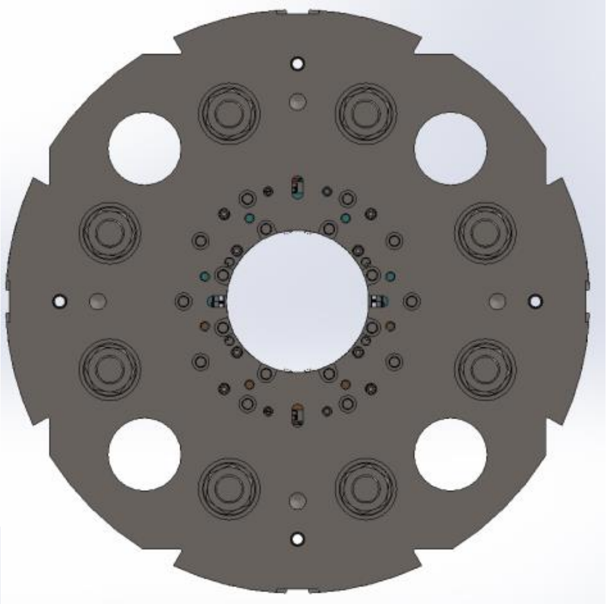
Next tasks: magnet fabrication

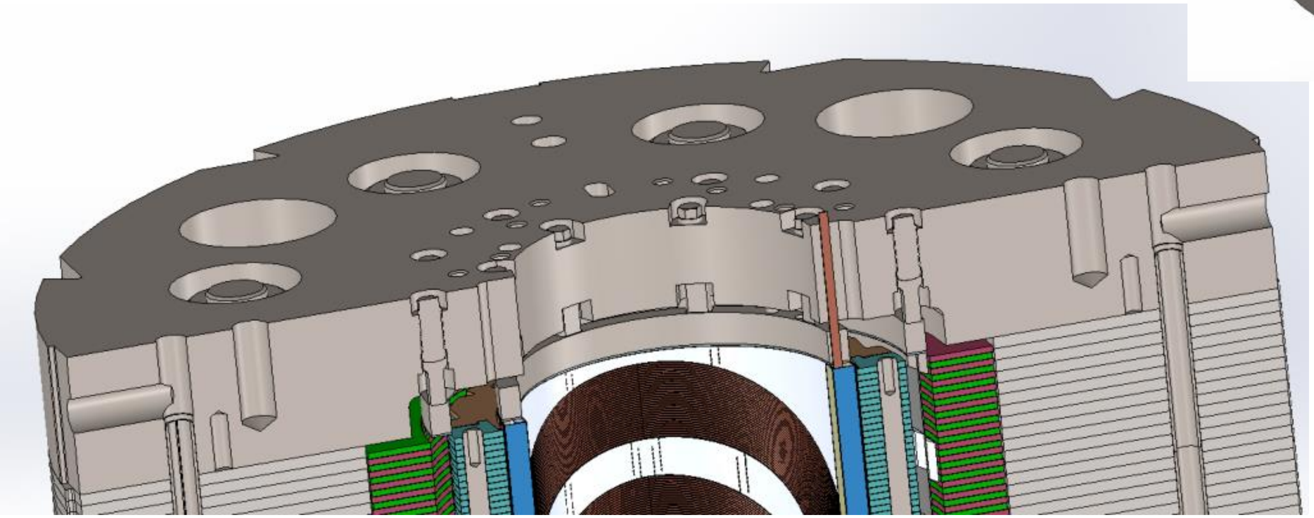
- Winding of the **first coil** will start on Oct, 16th.
- We have **cable** only for three coils.
- **End spacer** design will not be changed till the first coil is finished.
- The fabrication of some **tooling** will be launched before the end of October: kapton pre-forming, collaring shoe bending, inner dipole assembly.
- The orders for the fabrication of the tooling for the **outer dipole** are waiting for the feedback of the inner dipole production.

Next tasks: endplate design

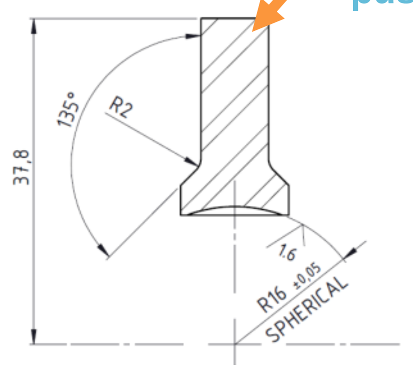
- In order to hold the longitudinal forces, **thick endplates** are necessary. Design is under final review. They will be already used for the inner dipole cold test.

- **Instrumentation** on collars and end pushers will be made at CERN Mechanical Measurement Laboratory. Six collar sections and one coil of each dipole will be monitored. About six hundredth wires!!

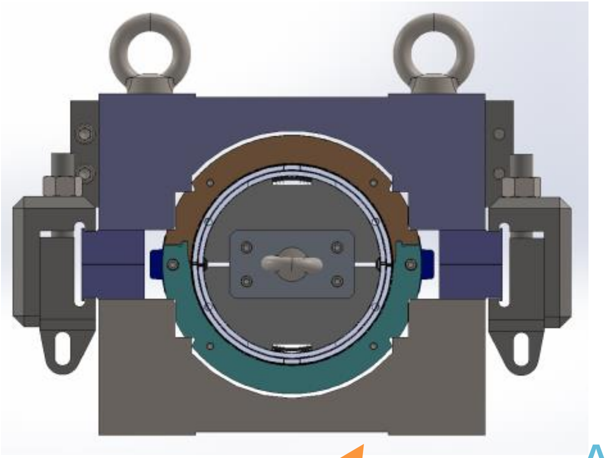


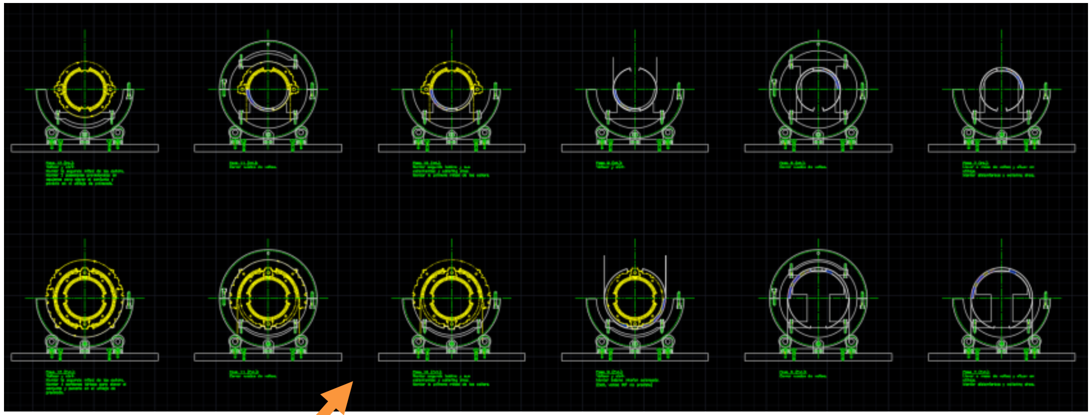


Longitudinal pusher



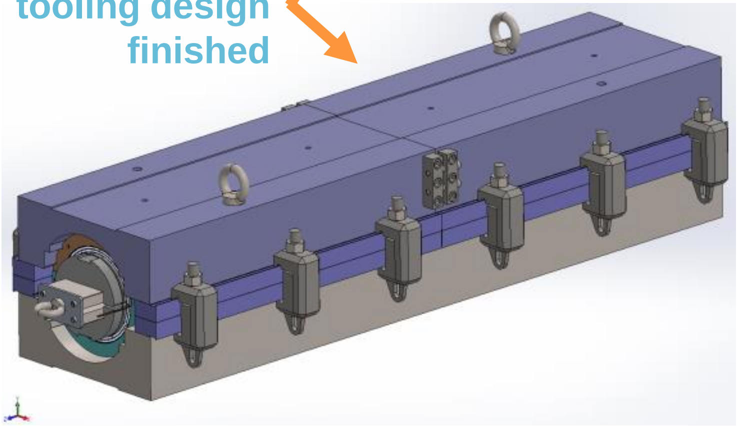
Next tasks:
Collaring and assembly tooling



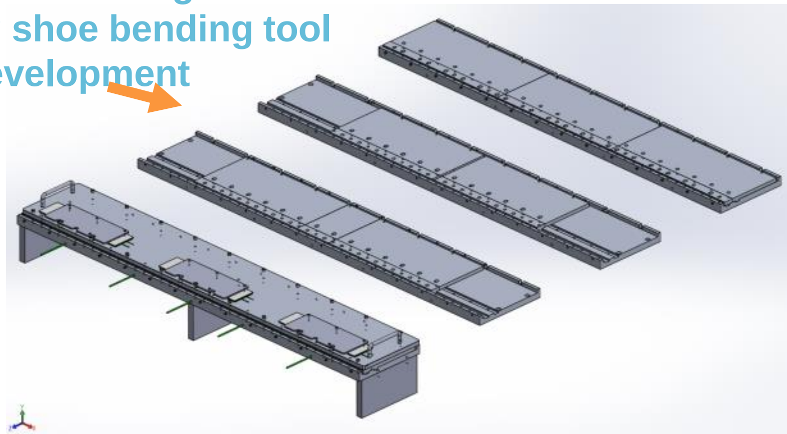


Assembly procedure and tooling design ongoing

Inner collaring tooling design finished

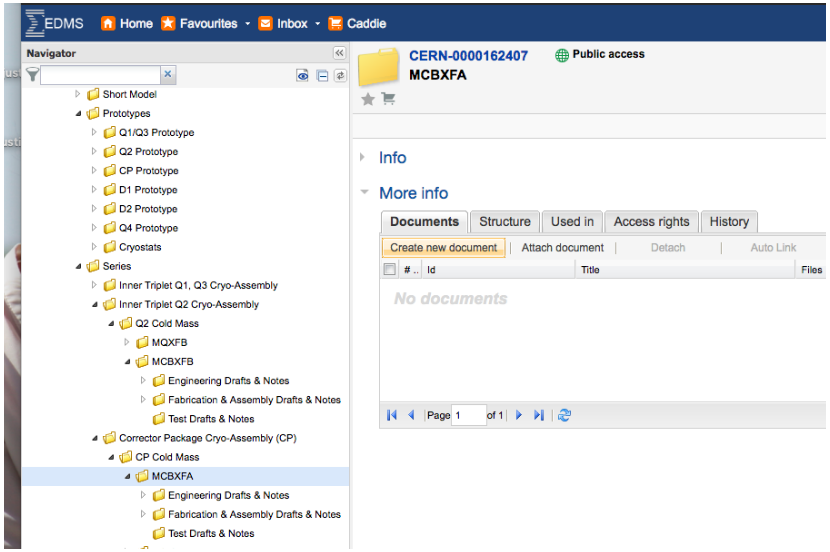


Kapton pre-forming and collaring shoe bending tool under development



Next tasks: Quality Control

- The structure at EDMS has been created
- The equipment codes for **CDD** storage have been created. About 500 drawings of the short mechanical model and the inner dipole tooling have been already sent to CDD team.
- The **MTF** equipment codes are also being generated.



- Equipment codes for CDD
  - LHCMCBXFA (MCBXFA magnet: 11 digits + 4 digits for drawing number)
  - LHCMCBXFAC (MCBXFA coil assembly & components)
  - LHCMCBXFB (MCBXFB magnet)
  - LHCMCBXFT (MCBXFA & B generic tooling)
    - LHCMCBXFT001_E9001 (Pay-off machine)
    - LHCMCBXFT002_E9002 (Take-up machine)
    - …
  - LHCMCBXFMM (Short mechanical model)
  - LHCMCBXTMT (tooling for short mechanical model)

- Equipment code for MTF
  - HCMCBXFA001-E9xxxxxx (E9:CIEMAT, MCBXFA magnet)
  - HCMCBXFAC001-E9xxxxxx (MCBXFA Inner collared coil)
  - HCMCBXFAC002-E9xxxxxx (MCBXFA Inner coil)
  - HCMCBXFAC003-CRxxxxxx (MCBXFA collared coil components).
    - The number 00X will increase by each different component
  - HCMCBXFA001-E9xxxxxx (MCBXFB magnet)
  - HCMCBXFAC001-E9xxxxxx (MCBXFB Inner collared coil)
  - HCMCBXFAC002-E9xxxxxx (MCBXFB Inner coil)
  - HCMCBXFAC003-CRxxxxxx (MCBXFB collared coil components).

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Schedule

		April 2017	Oct 2017
Design	Detailed mechanical calculations	Done	Done
	ID fabrication drawings	Aug-17	Oct-17
	OD fabrication drawings	Aug-17	Dec-17
Fabrication	Cable MCBXB H+V delivered (4 ID + 3 OD unit lengths)	June-17	Oct-17
	Winding machine ready	Apr-17	Jun-17
	First winding test	May-17	Sept-17
	First ID coil	Jul-17	Nov-17
	ID coils	Sep-17	Jan-17
	ID Collaring	Oct-17	Feb-18
	ID Magnet assembly	Oct-17	March-18
	OD coils	Feb-18	April-18
	OD Collaring	Mar-18	May-18
	Magnet Assembly	April-18	June-18
Test	ID in vertical cryostat	Dec-17	April-18
	Magnet prototype in vertical cryostat	May-18	July-18

Conclusions

- Fist winding and binding tests has been successfully performed.
- First coil winding will start on Oct 16th.
- The design of the magnet is almost finished. The assembly tooling design is ongoing.
- The manufacturing drawings of the outer dipole tooling are waiting for feedback from the inner dipole production.
- Despite the limited manpower resources, we are doing our best to minimize the delays.

Thank you for your attention