Babcock Noell GmbH

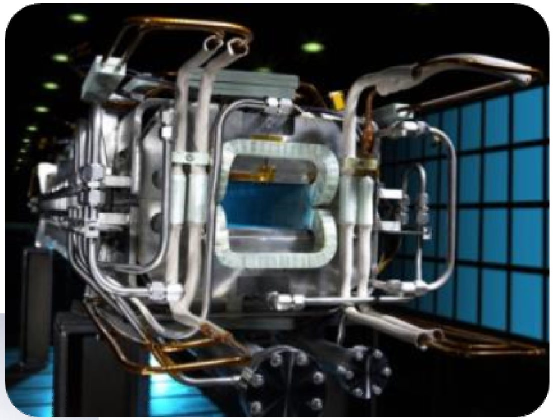
Development and Series Production of LHC and FAIR Accelerator Magnets in Industry

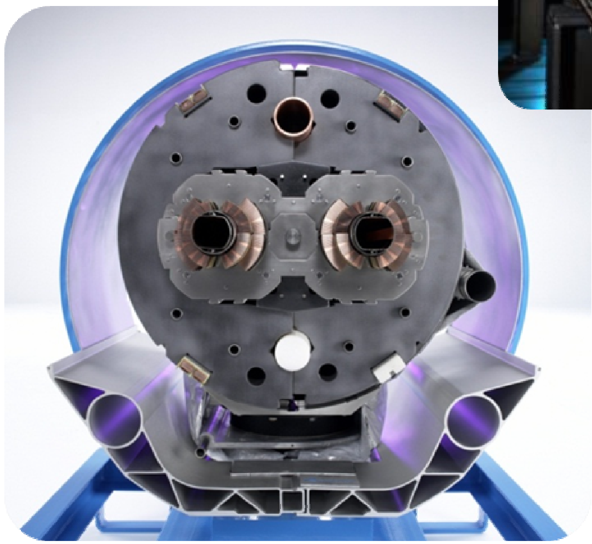
W. Walter - ACADEMIA-INDUSTRY MATCHING EVENT - Madrid

2013-05-27

Outline

1. Introduction
   - Babcock Noell GmbH
   - LHC and FAIR
   - Industrialization Process
2. Production of LHC Main Dipoles
   - From Prototypes to Series
   - Best Practice Sharing
3. Status of FAIR SIS100 Dipole Production
4. Conclusions





Babcock Noell: Member of Bilfinger SE

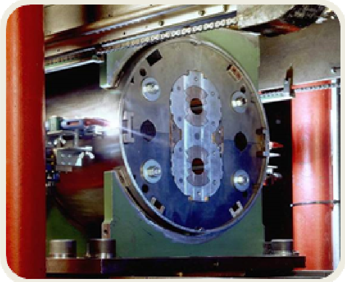
Bilfinger SE

Bilfinger Power Systems GmbH

- Energy Technology
- Piping Technology
- Nuclear- & Environmental Technologies
  - Babcock Noell GmbH
- Machinery- & Apparatus Engineering
- Power Plants

Nuclear Services

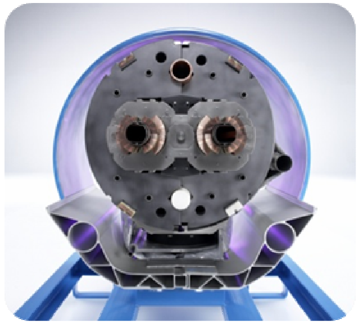
Nuclear Technologies



Magnet Technologies

Environmental Technologies

Babcock Noell: Large Scale Projects



LHC
1999

HERA
1986

W7-X
1998

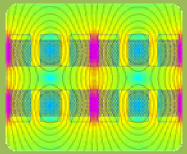
FAIR
2012

Babcock Noell: Functional Systems

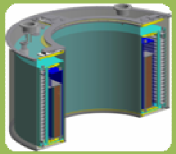
Idea → Conceptual Design → Engineering Design → Prototyping → Your Product

SC Undulators

SC Undulator/ Wiggler

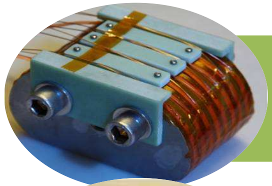


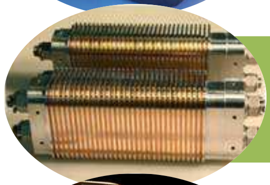
VATESTA

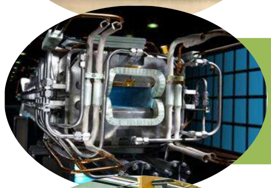


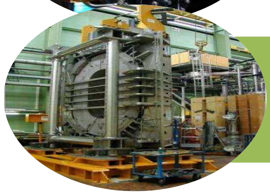
Spin-Echo Spectrometer

Babcock Noell: Prototypes


HTS Undulator


SC Undulators


SIS 100


TFMC


DEMO Coil W7-X


Dipole and Components for LHC


PM Undulators


Current Leads

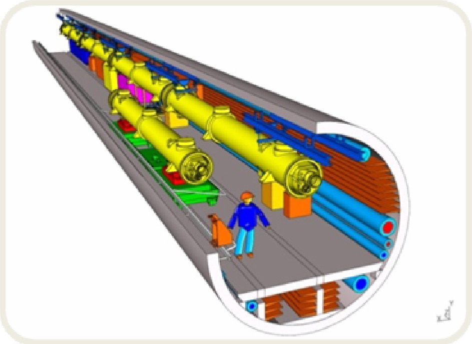
LHC

Babcock Noell: Studies

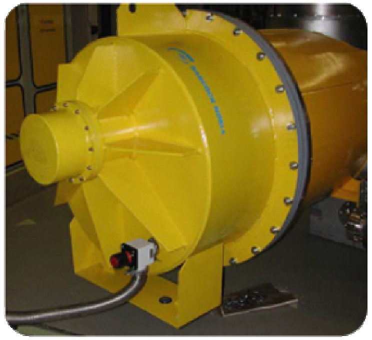
Feasibility Studies

Industrialization Studies

Cost & Schedule Studies

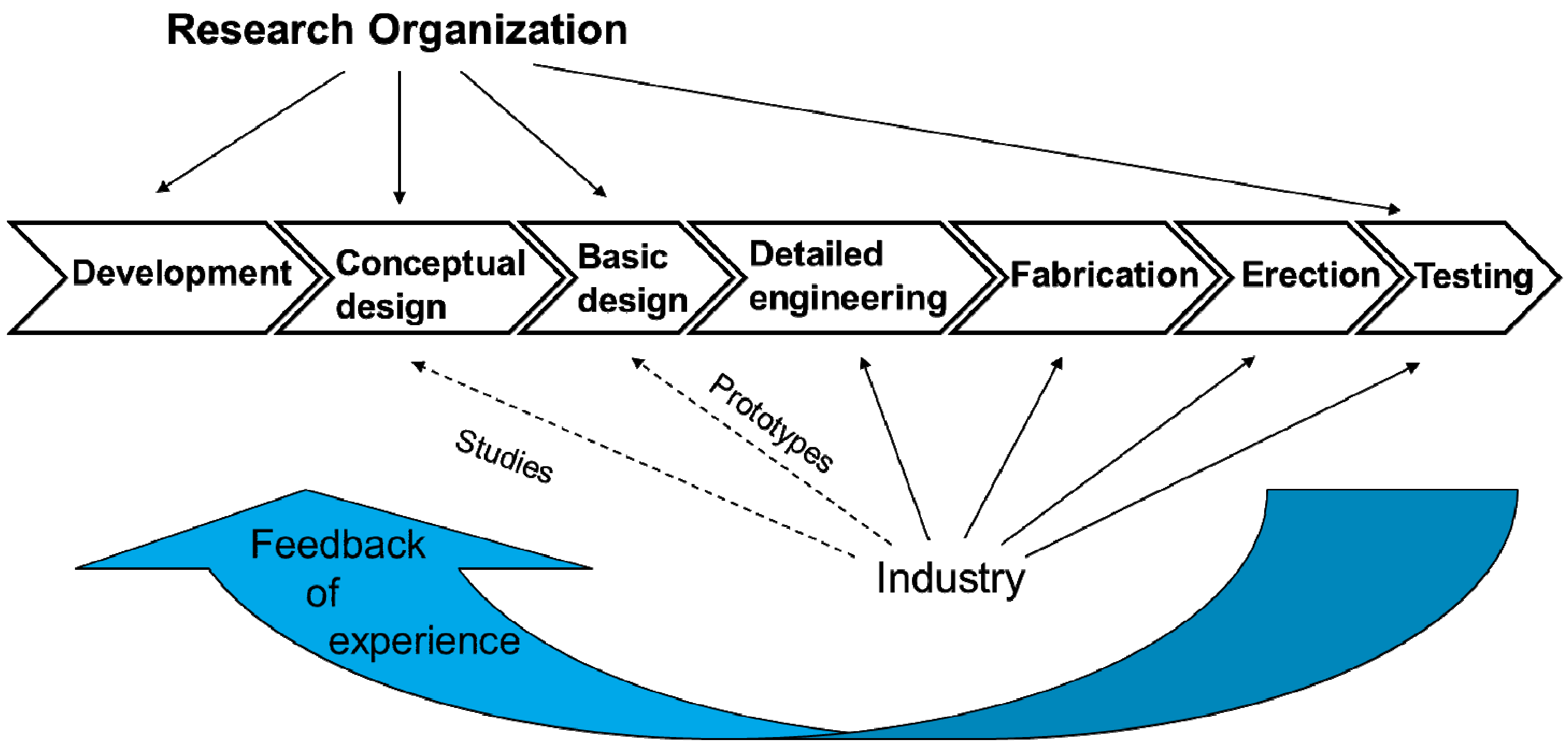


Series production for TESLA, XFEL, ILC



Transportation of cryomodules for XFEL

Collaboration: Research Organizations & Industry



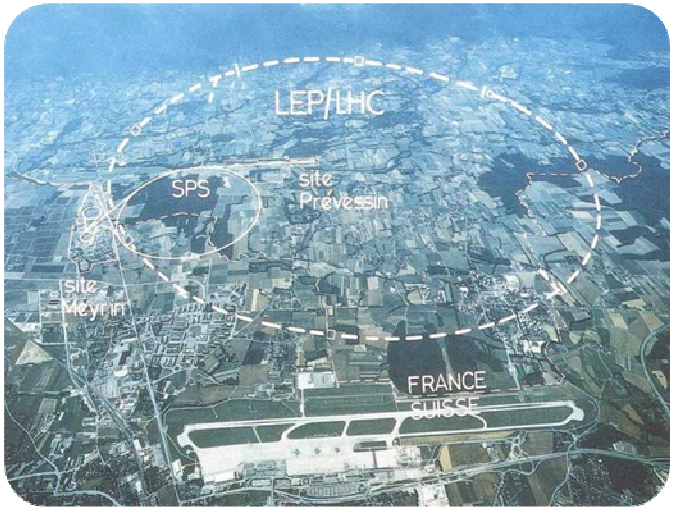
LHC Project at CERN & FAIR at GSI

Large Hadron Collider:

•the world‘s largest and most powerful particle accelerator

•probes the fundamental structure of the universe

•world‘s biggest superconducting machine

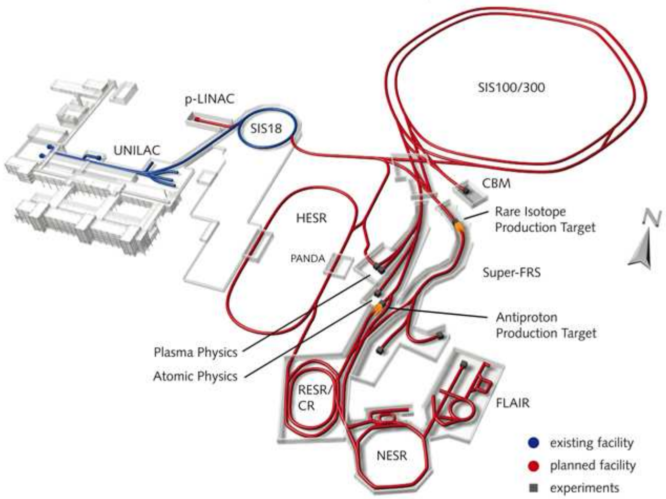


FAIR: Facility for Antiproton and Ion Research:

•new international accelerator facility

•will provide antiproton and ion beams of high intensity and quality

•SIS100: Heavy Ion Synchrotron



LHC Main Dipoles

Twin aperture design cos-theta design

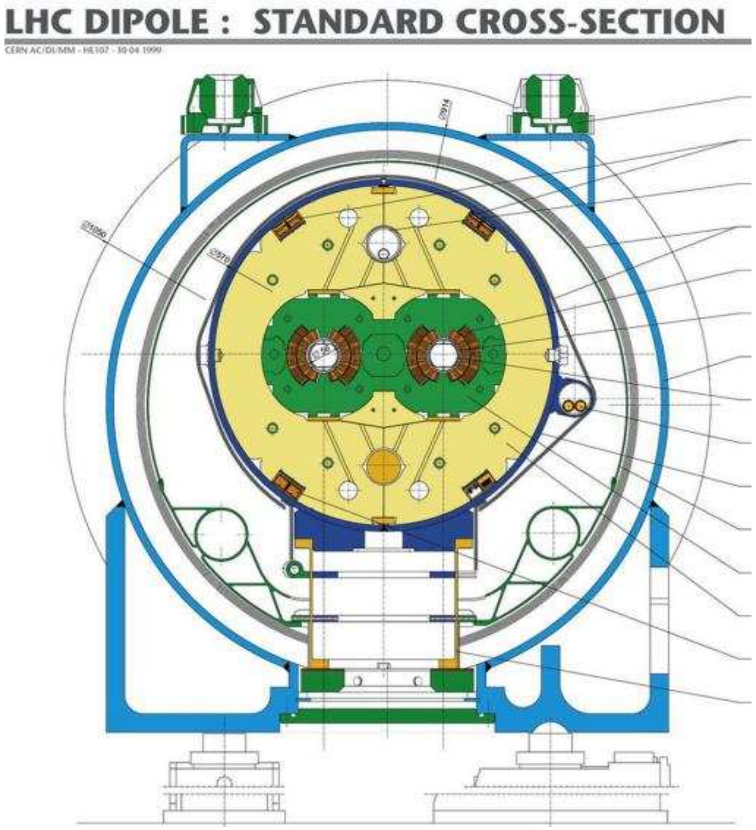
•high field quality

•high magnetic field

•Working current: 11.8 kA

•Operating temperature: 1.9 K

•Nominal magnetic field: 8.33 T



FAIR SIS100 Dipoles

Superferric windowframe design

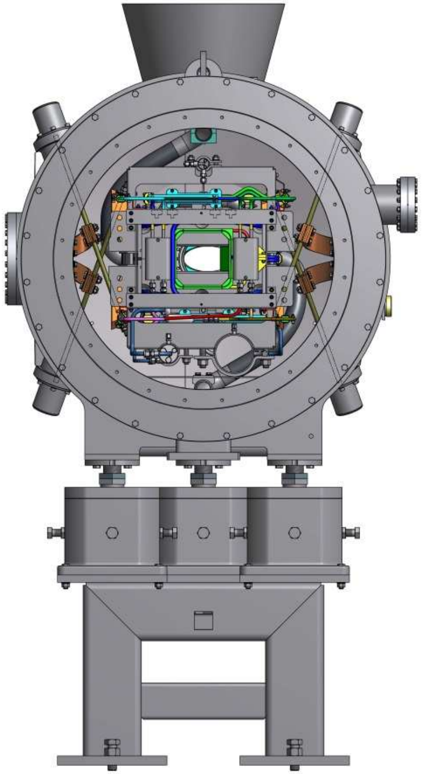
•high field quality

•fast periodic ramp rate (1.9 T, 4 T/s, 1 Hz)

•Working current: 7 kA

•Operating temperature: 4.2 K

•Nominal magnetic field: 1.9 T



Comparison of Dipoles from Industrial Point of View

Parameter	LHC Main Dipoles	SIS100 Dipoles
Number units	3 x 416	108
Scope	Cold mass	Cold mass, cryostat, girder
Design	Cos theta	Windowframe
Cable	Rutherford	Nuklotron cable
Length	15 m	3 m
Weight	15 t	2 t + 2 t

Many differnces but one common goal:
cost effective series production in time and quality

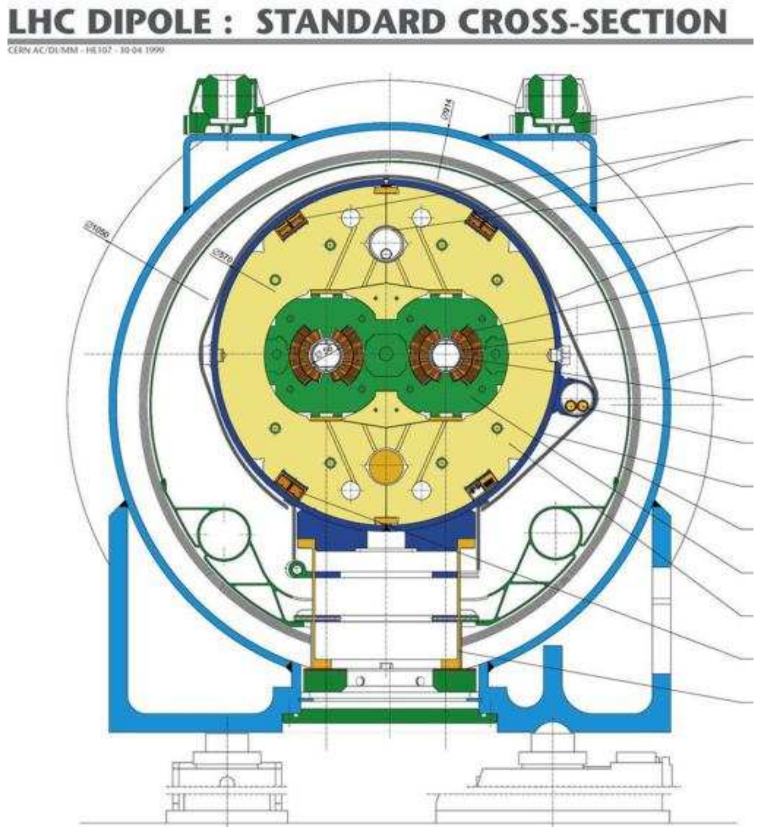
→ Industrialization strategy is essential.

The Industrialization Process

1. Design & development phase ⟶ definition of requirements for product
2. Prototype phase ⟶ verification of detailed design
3. Pre-series phase ⟶ validation of fabrication according to final design
4. Series production ⟶ production of the product in time, quality and cost

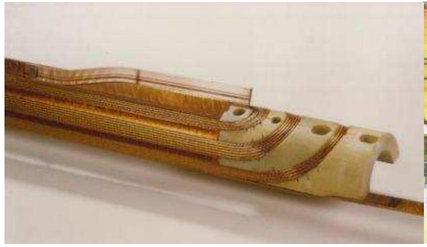
Phase	LHC	SIS100
Design & development	1990-1999: cold mass, collared coil, … up to 10 m long	2005-2009: EU 6th Framework Programm incl. mock-ups
Prototype	1999: 2 x 15 m prototypes	2007-2008: 1st industrial prototype
Pre-series	1999-2002: 30 pre-series magnets (per supplier)	2012-2013: First Of Series (FOS) magnet
Series	2002-2006 series production	Series Production 2014

LHC Main Dipoles



Development of LHC Dipoles at Babcock Noell

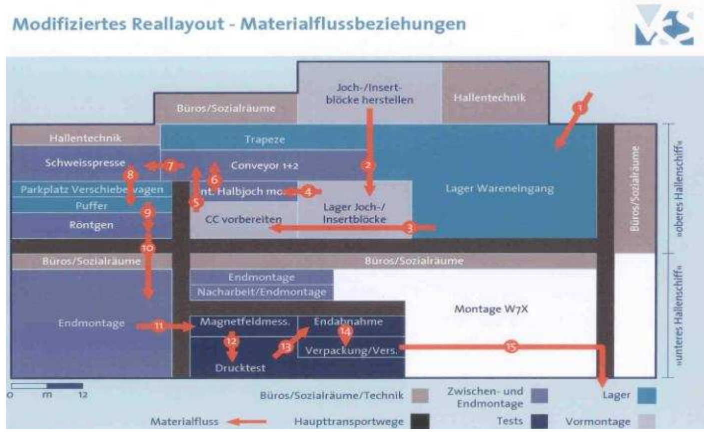
- Independent contracts for the development and the construction of prototype magnets and tools between 1990 and 1999 for Babcock Noell:
  - 6 prototype dipole magnets
  - 15m long winding and curing tools
  - Multifunctional press (force 270 MN)
  - 20m long PLC-controlled winding machine
  - Production of prototype cryostats for dipoles



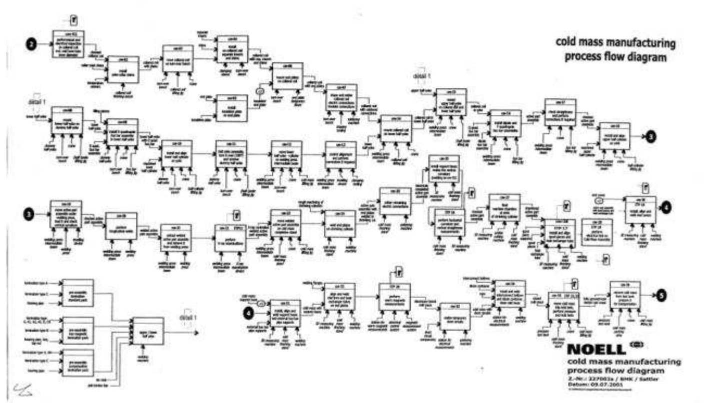

Similar dipole development activities of CERN together with other industrial partners: Alstom, Ansaldo, Elin

From Prototypes to Industrial Production

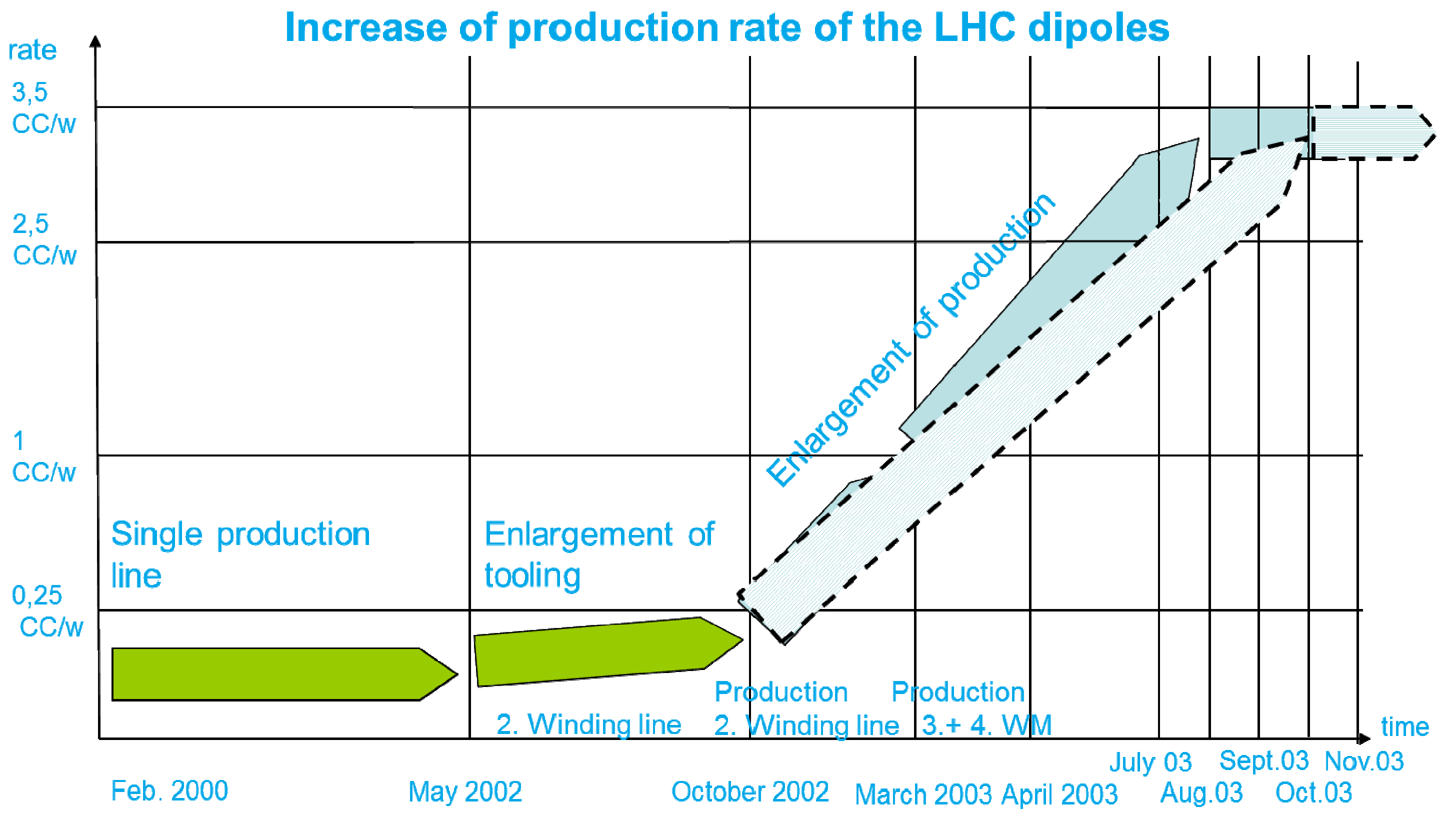
- 1990 – 1999: Development & Prototyping
- 1999 – 2002: Pre-Series
- 2002 – 2006: Series Production



Transition from prototype to (finite) series production needs careful planning (facilities incl. layout, man power, tooling, ramp-up and ramp-down concept etc.)



LHC Fabrication Commitment

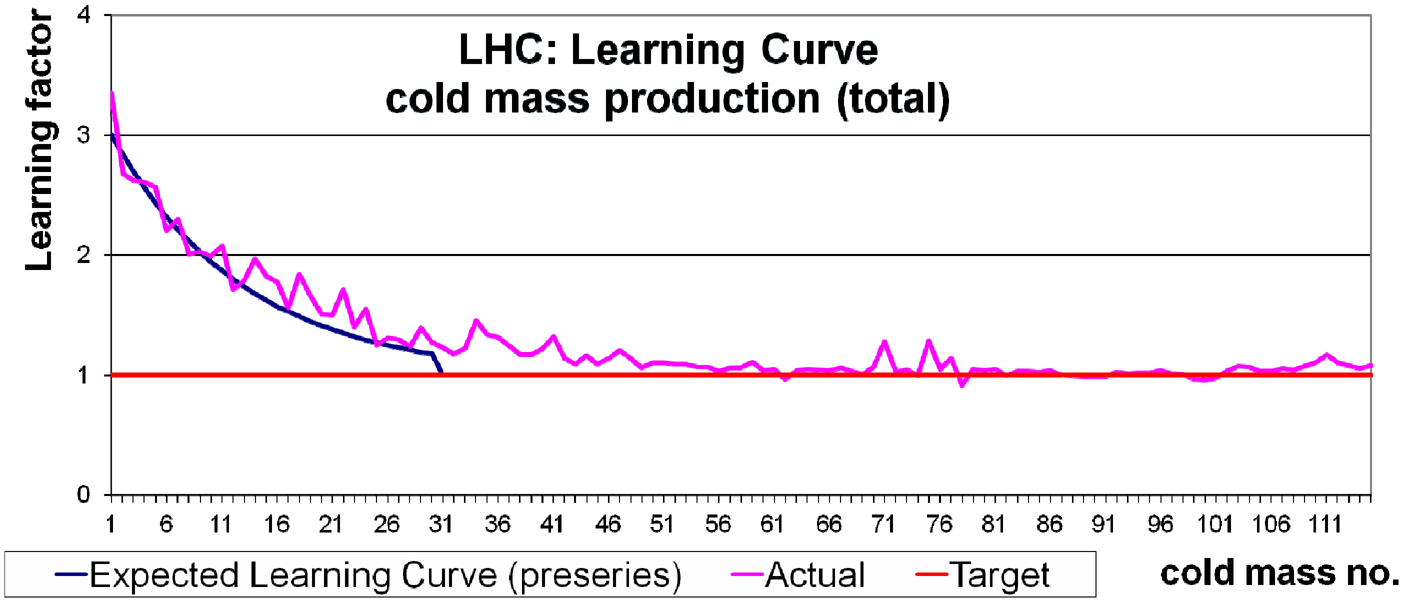


Impressions from LHC Main Dipole Production at Babcock Noell

Production area ~10,000 m^2

Nearly 200 employees worked in two shifts

Mission Accomplished



Dipole Production: Main Issues

- Mastering key technologies
- Optimising fabrication layout and logistics
- Excellent QA
- Organisation and good management
- Staff dedication
- Best Practice Sharing with former competitors

⟶ *Completing the contract 7 months ahead of schedule*

Babcock Noell

was honoured with the

GOLDEN HADRON AWARD

by CERN

Best Practice Sharing: Precondiction

Best practice sharing: A technical exchange between companies in the interest of the project.

Precondition:

▪Several companies produce (nearly) the same product

▪Competition phase is finished, i.e. contracts are placed by the customer

▪Customer and companies agree to a best practice sharing process

▪Core know-how which differentiates companies is not affected

▪Comparable competence of companies

Best Practice Sharing: Example LHC Dipoles

Contractual Situation:

- 3 Suppliers: Alstom, Ansaldo, Babcock Noell

  manufacturing the same amount of an identical product:

  - 1999: Pre-Series Contract for 30 Cold Masses each
  - 2002: Series contract for 386 Cold Masses each
- Manufacturing including tooling within responsibility of suppliers
- Various material (Rutherford Cable, Joke Sheets, ...) and measurement equipment supplied by the customer

Best Practice Sharing: Example LHC Dipoles

Best Practice Sharing Process:

- Process started on initiative of Babcock Noell with support by CERN
- Triggering event:

  For problem with soldering of layerjump and insulation quality, CERN actively initiated exchange between companies
- Various meetings between the 3 suppliers (bilateral and all parties) at their respective fabrication sites
- Meetings consisted of:

  site visit, mutual presentations on project progress and discussion

Layerjumps on LHC main dipole winding package

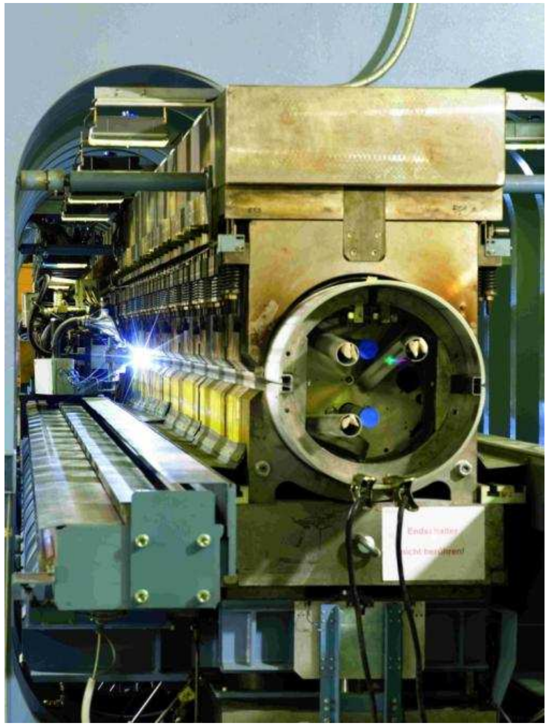
Best Practice Sharing: Example LHC Dipoles

BILFINGER POWER SYSTEMS

Benefit from Best Practice Sharing - Examples:

- Welding process for shrinking cylinder improved with CERN:

  solution distributed via best practice sharing
- Avoiding of interruption in the production process by exchange of: copper wedges, endspacers, collars, coil protection sheets, ...
- Alternative supplier for: diode-container, turn over device for cold mass, quenchheaters, ...



Welding of LHC main dipole cold mass

Best Practice Sharing: Companies Exchange

Exchange between companies in the interest of the project:

- Goals:
  - Exchange on technical information with respect to the production, tooling and material
  - Discussion on the project status (excluding commercial issues)
  - Mutual support in acquisition of material and tooling
  - Mutual support in case of material shortage or production bottlenecks

- Information exchange is at best a direct exchange of the people doing the job, i.e.:
  - Mutual visits of the fabrication of the other companies
  - Personal discussion between project managers, heads of production, main technicians


Manufacturing of LHC main dipoles

Best Practice Sharing: Benefits

Benefit for the customer:

- Repetition of mistakes is avoided → higher quality of the final product
- Production process is optimized due to mutual learning → acceleration of delivery time
- More uniform products from the various companies

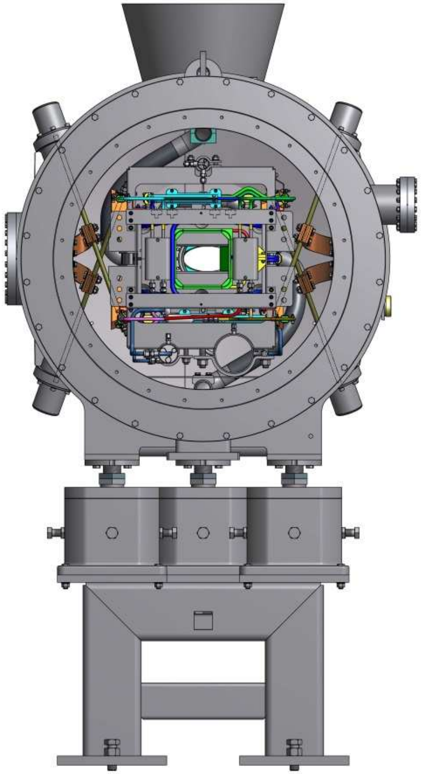
Benefit for the companies:

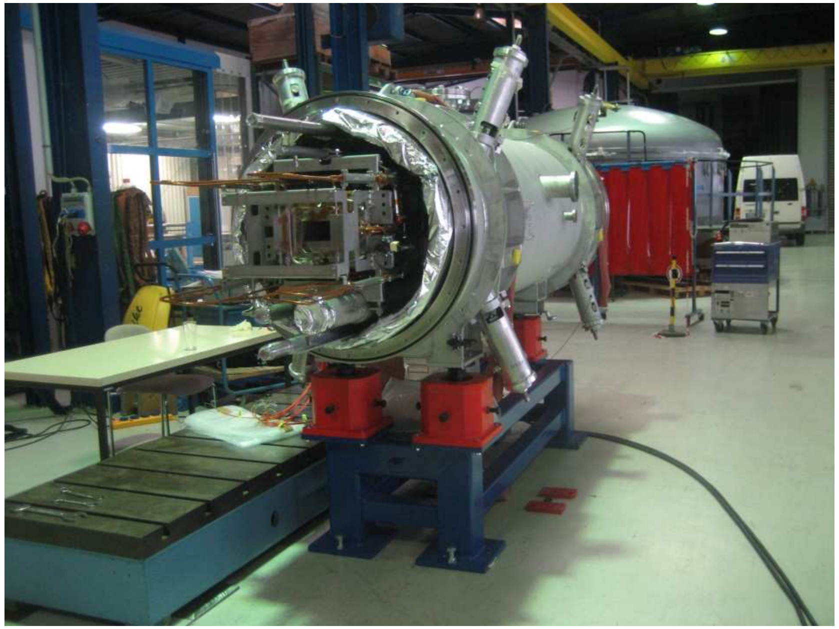
- Higher quality of the final product → satisfied customer
- Acceleration of delivery time → reduced cost due to reduced project duration
- Additional back-up solutions for shortages and bottlenecks

Benefit for both sides:

- Direct exchange with no intermediate customer, i.e. → no loss of information or possible misunderstanding
- Purely technical exchange, alternative solutions from others may be used or not, without discussion on contractual obligations, responsibilities etc.

FAIR SIS100 Dipoles





SIS100 Dipole Prototype and FOS Magnet

Significant design improvement:

2-layer straight magnet -> 1-layer curved magnet

Advantages:

▪4 times lower hydraulic resistance of coil
-> ramping with continuous triangular cycling mode @ 4 T/s

▪Reduction of peak field to 1.9 T
-> reduction of field errors due to iron saturation limit

-> New challenges in manufacturing:

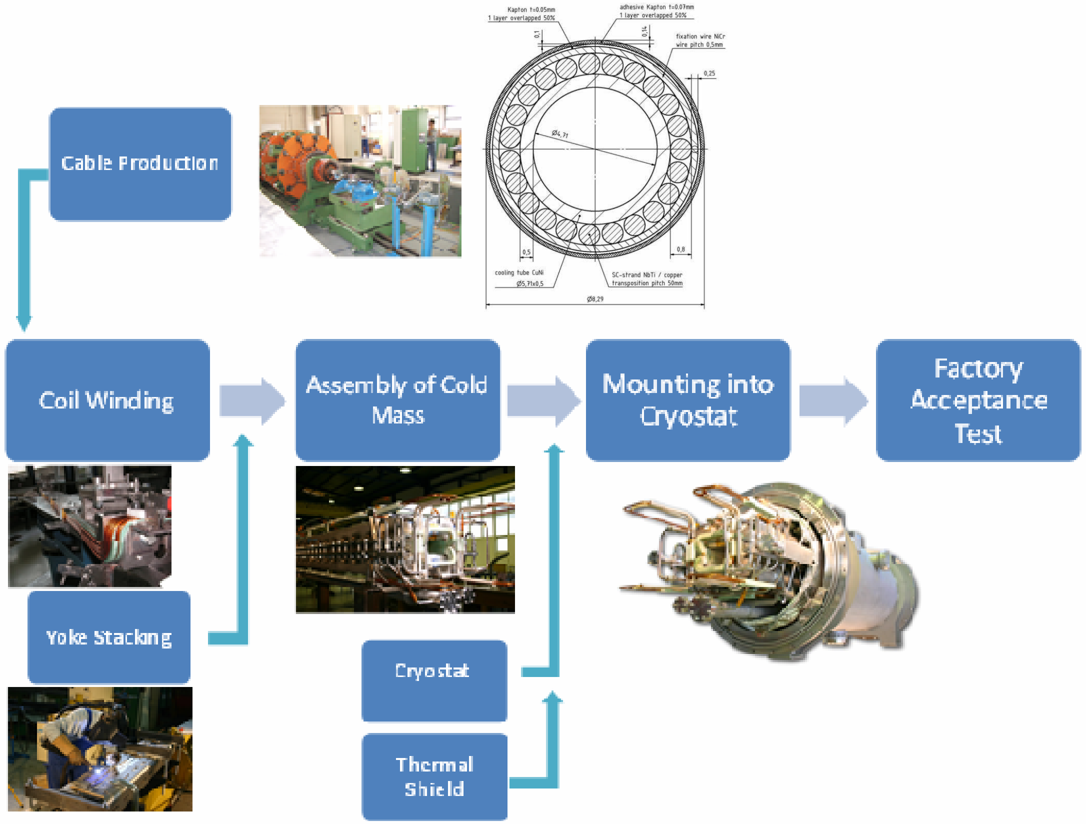
▪winding of bend coil and stacking of bend yoke

▪increased cable diameter reduced available space for electrical insulation and structural components in the coil

Parameter	Prototype	FOS
Effective length	2.756 m	3.062 m
Bending angle	0 deg	3.33 deg
Bmax	2.1 T	1.9 T
Max. ramp rate	4 T/s	4 T/s
Layers*turns	2*8	1*8
Operating current	7 kA	13 kA
Outer diameter of cooling tube	5 mm	5.7 mm
Number of strands	31	23
Strand diameter	0.5 mm	0.8 mm
Cable diameter	7.36 mm	8.29 mm

FOS Magnet Manufacturing Workflow

BILFINGER POWER SYSTEMS



FOS Magnet: Cable Production

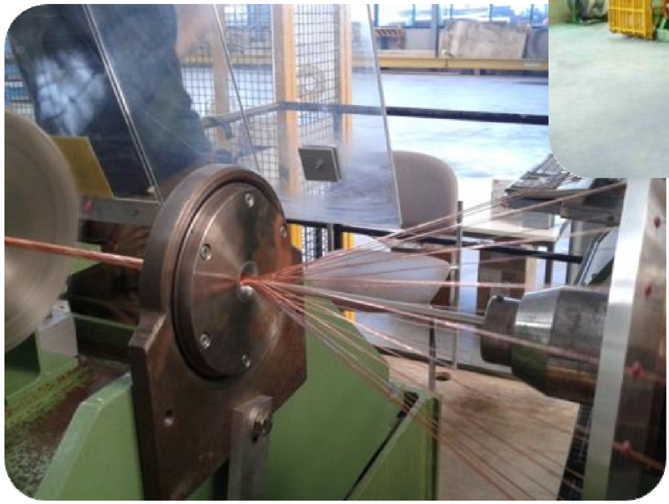
Demand of cable per dipole: 62 m (coil) + 52 m (busbars).

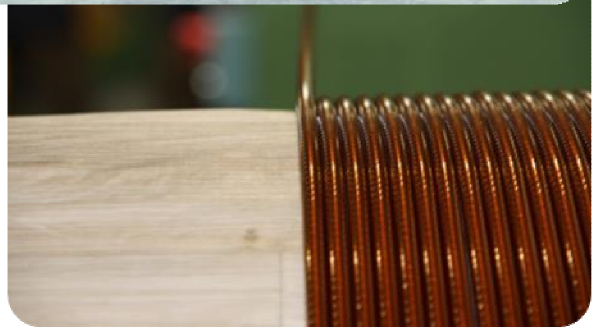
Cable produced for 1 dummy coil with copper strands.

In total 265 m of SC Nuclotron type cable produced.

$\upsilon_{Spinner}$ = 705 rpm

v_{Cable} = 0.35 m/min





FOS Magnet: Test Winding and Dummy Coil

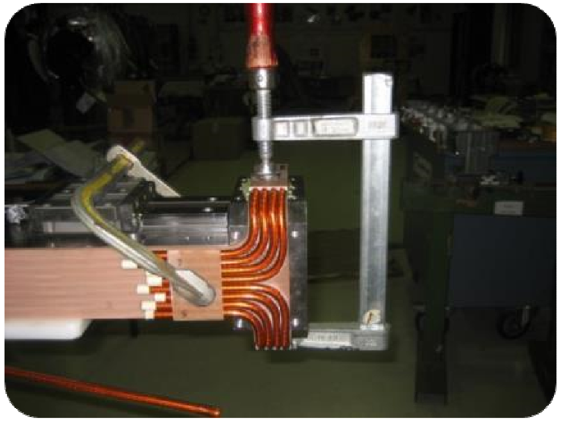
Precisely machined G11 elements

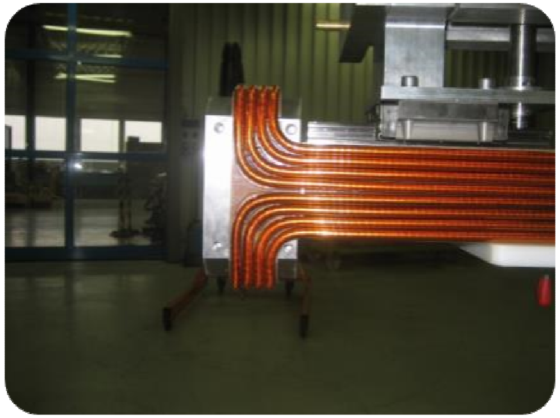
▪define position of turns with respect to each other and to yoke

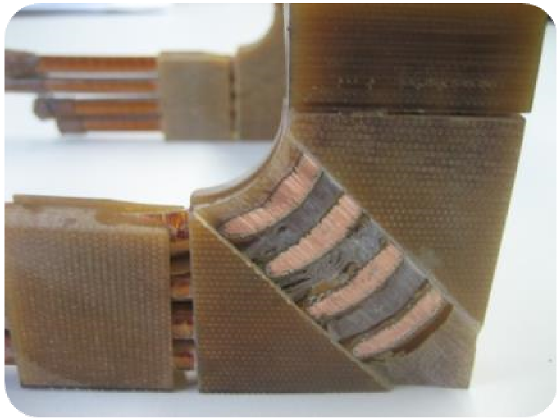
▪avoid relative motions in operation

Cable is glued into G11 to achieve a monolithic block

Prepreg used in coil head area

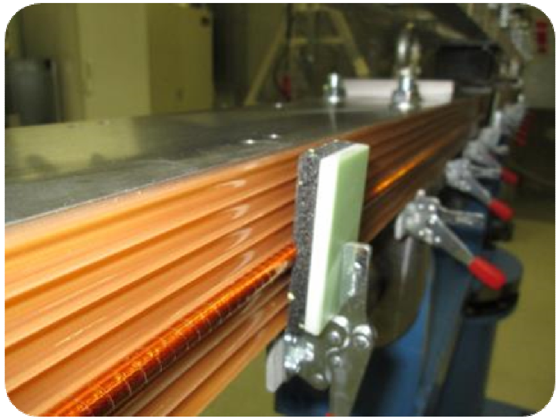


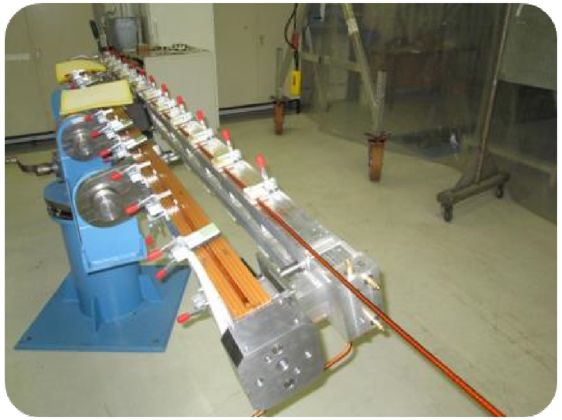


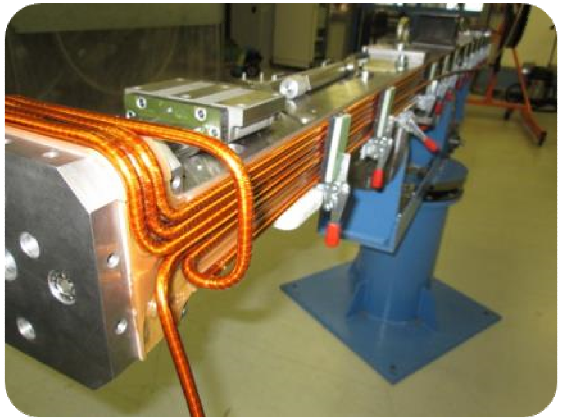


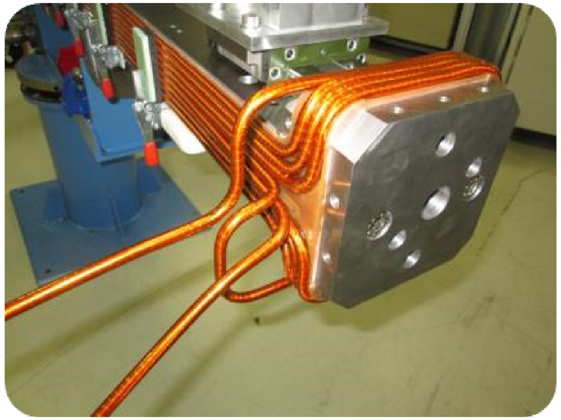
FOS Magnet: Coil Winding on Winding Tool

Winding tool developed for bent single layer FOS coil,
same concept as for Prototype coil









FOS Magnet: Gluing of G11 Structure with Coil

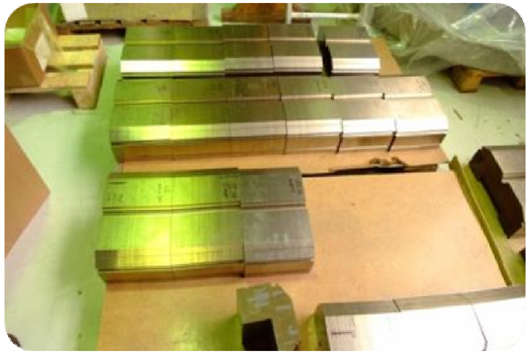
t ~ 5 h
T ~ 180 °C

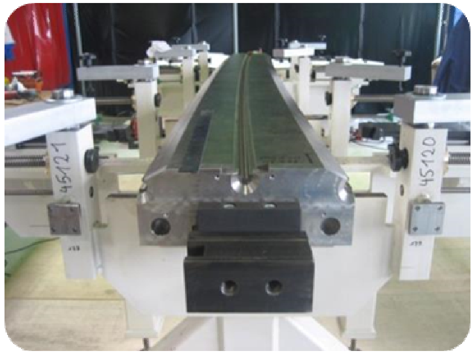
FOS Magnet: Coil Prepreg Impregnation

t ~ 3.5 h
T ~ 150 ℃

FOS Magnet: Yoke Manufacturing

Lamination: M600-100A, 1mm, Stabolit 70 coating





Yoke Manufacturing:

1.Stack 200 mm curved packages, filling factor ≥ 98%

2.Glue packages in oven

3.Place packages on girder

4.Adjust filling factor

5.Insert cooling tubes

6.Weld side and top covering sheets

FOS Magnet: Assembly of Cold Mass

Assembly of coil and half yokes on rotating device

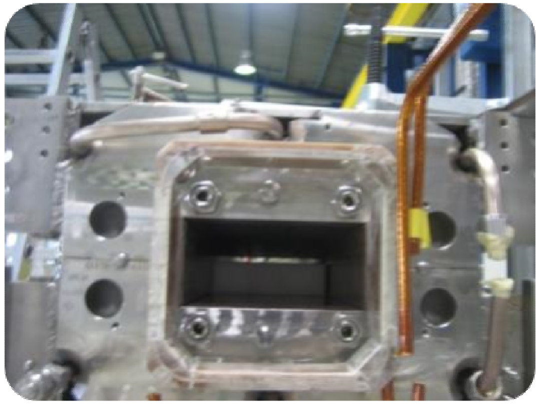
Installation of:

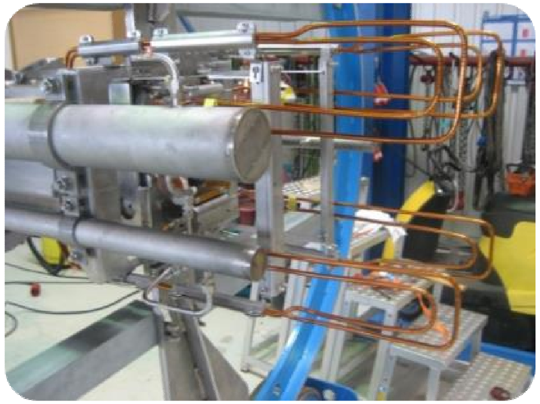
▪Busbars

▪Potential breaks

▪Instrumentation

▪Helium supply-lines





FOS Magnet: Assembly of Magnet

Assembly on dedicated rig:

1.Place thermal shield in cryostat

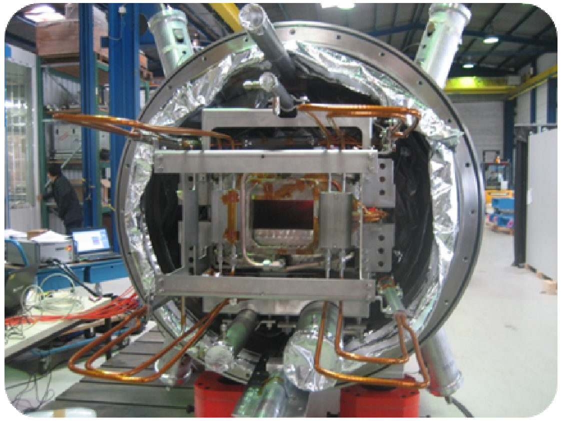
2.Pull magnet into cryostat and suspend on rods

3.Align with laser-tracker

Current status:

Assembly finished.

Delivery to GSI: June 3rd 2013.



Outlook on Series Production

Next step: test of FOS Magnet at GSI:

▪Magnet training

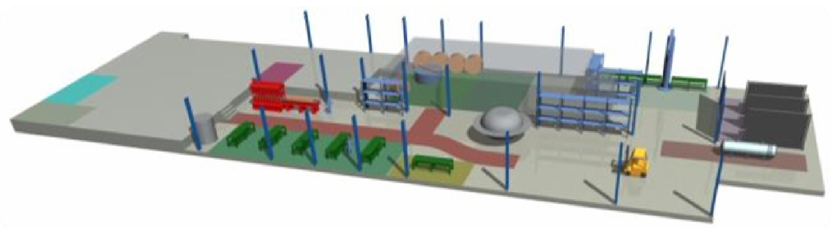
▪AC loss

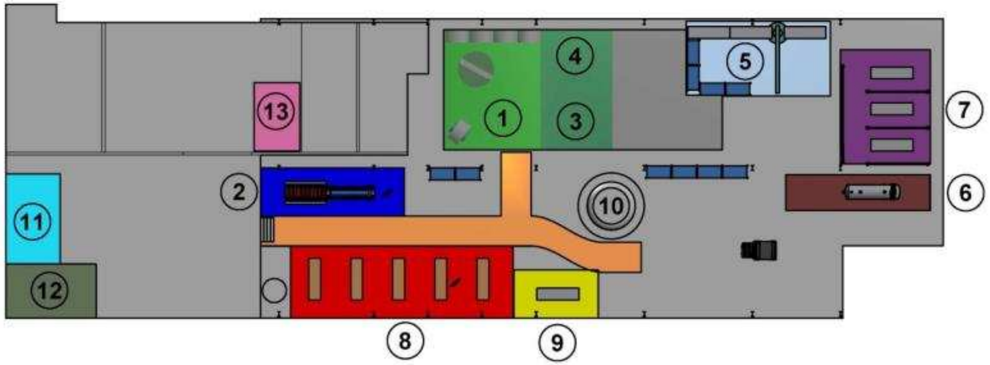
▪Hydraulic resistance

▪Quench performance after one thermal cycle

Series Production:

Experience from FOS -> optimise series production.





Manufacturing layout for SIS100 series production:
1 = winding, 2 = baking press, 3= coil insulation,
4 = electrical tests of coils, 5 = stacking of yoke packages,
6 = yoke heat treatment, 7 = assembly of half-yokes,
8 = assembly of cold mass into cryostat, 9 = geometrical measurements,
10 = He leak test on coils, 11 = pre-manufacturing of busbars,
12 = leak tests on components,
13 = thermal shield manufacturing

Conclusions

Cost effective series production is a strength of industry. To exploit this, a **strategy for industrialization** is **needed**.

Concepts from LHC Main Dipoles have been applied to FAIR SIS100 Dipoles.

Best practice sharing is of advantage for customer and suppliers when applicable

Challenges in **manufacturing of the SIS100 FOS magnet** have been overcome to **qualify the manufacturing process for the series production**.

Next important step: FOS Magnet tests at GSI for final verification of series design and manufacturing concept.

Babcock Noell GmbH

Alfred-Nobel-Str. 20
97080 Würzburg
Germany

Phone +49 931 903-6054
Fax +49 931 903-6010

Wolfgang.Walter@bilfinger.com
www.bng.bilfinger.com

Registered at Local Court Würzburg, HRB 7156
VAT-Id. No.: DE211420259

Executive Management:
Helmut Welp, Chairman
Dr. Ronald Hepper
Peter Stephan

Thank you for your attention