HOW TO PRODUCE
100 SUPERCONDUCTING MODULES
FOR THE EUROPEAN XFEL
IN COLLABORATION AND WITH INDUSTRY

Hans Weise, for the Accelerator Consortium

Courtesy: with many pictures from D. Noelle / DESY & others incl. E. Zanon & Research Instruments
Some specifications

- Photon energy 0.3 - 24 keV
- Pulse duration ~ 10 - 100 fs
- Pulse energy few mJ
- Superconducting linac. 17.5 GeV
- 10 Hz (27 000 b/s)
- 5 beam lines / 10 instruments
  - Start version with 3 beamlines and 6 instruments
- Several extensions possible:
  - More undulators
  - More instruments
  - ……..
  - Variable polarization
  - Self-Seeding
  - CW operation

First electron beam 2nd half of 2016

SASE2

SASE1, $\lambda_u = 40$ mm
0.2 – 0.05 nm

SASE3, $\lambda_u = 68$ mm
1.7 – 0.4 nm
100 s.c. Modules for the European XFEL

An Accelerator Complex for 17.5 GeV

100 accelerator modules

800 accelerating cavities
1.3 GHz / 23.6 MV/m

25 RF stations
5.2 MW each
100 accelerator modules

800 accelerating cavities
1.3 GHz / 23.6 MV/m
100 s.c. Modules for the European XFEL

Production of Accelerator Components

IPAC Conference – 18 June 2014
Hans Weise, DESY
100 s.c. Modules for the European XFEL Installation

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Installation Test
100 s.c. Modules for the European XFEL

XFEL Accelerator Module with Tailored Waveguide System
## Contributions to the European XFEL Modules

<table>
<thead>
<tr>
<th>Institution</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>BINP Novosibirsk, Russia</td>
<td>• cold vacuum bellows</td>
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<tr>
<td></td>
<td>• coupler vacuum line</td>
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<tr>
<td>CEA Saclay / Irfu, France</td>
<td>• cavity string and module assembly</td>
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<tr>
<td></td>
<td>• cold beam position monitors</td>
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<tr>
<td></td>
<td>• magnetic shields, superinsulation blankets</td>
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<tr>
<td>CIEMAT, Spain</td>
<td>• Superconducting magnets</td>
</tr>
<tr>
<td>CNRS / LAL Orsay, France</td>
<td>• RF main input coupler incl. RF conditioning</td>
</tr>
<tr>
<td>DESY, Germany</td>
<td>• cavities &amp; cryostats</td>
</tr>
<tr>
<td></td>
<td>• contributions to string &amp; module assembly</td>
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<tr>
<td></td>
<td>• coupler interlock</td>
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<td></td>
<td>• frequency tuner</td>
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<tr>
<td></td>
<td>• cold vacuum system</td>
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<tr>
<td></td>
<td>• integration of superconducting magnets / current leads</td>
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<tr>
<td>INFN Milano, Italy</td>
<td>• cold beam position monitors</td>
</tr>
<tr>
<td>Soltan Institute, Poland</td>
<td>• Higher Order Mode coupler &amp; absorber</td>
</tr>
<tr>
<td></td>
<td>• cavities &amp; cryostats</td>
</tr>
<tr>
<td></td>
<td>• contributions to frequency tuners</td>
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European XFEL requires **8 cavities & couplers** to build **1 module per week**

**Production Rate of Key Components**

- **European XFEL requires 8 cavities & couplers to build 1 module per week**

- **monthly average was to increased by approximately x 30**

*Graph showing the number of initial 9-cell cavity tests per year at DESY during TESLA / XFEL R&D.*

- **average 1 per month**

**Year:**


**Number of cavities:**

- 0, 5, 10, 15, 20, 25, 30, 35

**Number of initial 9-cell cavity tests per year at DESY during TESLA / XFEL R&D**

- **average 1 per month**

**monthly average was to increased by approximately x 30**
Cavity Production (here at Company RI)

all pictures courtesy Research Instruments
100 s.c. Modules for the European XFEL

Cavity Production (here at Company E. Zanon)
Two cavity vendors were contracted to produce 400 cavities each. A slight variation in final surface treatment was observed. All cavities were tested and partly re-treated/re-tested in collaboration of IFJ/DESY. Further assembly takes place at CEA Saclay/Irfu.
All Nb / NbTi material (24,420 single parts!) was procured by DESY.

Detailed quality inspection was developed and carried out.

All material available to cavity vendors.
Special CE certified machines were developed and given to industry.

Since accelerator cavities are delivered without performance guarantee, very detailed specifications are used.

Many productions steps are supported and partly supervised by DESY & INFN.

Several QC steps are established. Very detailed documentation.
Cavity Delivery Status as of 6/2014

- **total delivered to DESY**
- **total RF tested at DESY**
- **total delivery to IRFU**

**CVs Nr.**

- week 51
- week 3
- week 6
- week 10
- week 13
- week 16
- week 18/19
- week 22
- week 25
- week 28
- week 31/32
- week 35
- week 38
- week 41
- week 44
- week 47
- week 50
- week 1
- week 4
- week 7
- week 10
- week 13
- week 16
- week 19
- week 22

**Graph Details:**

- 8 cavities per week
- Problems with 2-phase line
100 s.c. Modules for the European XFEL

AMTF Test Stand Infrastructure
Mechanical production + surface treatment in full + standard operation

Vertical cavity testing and all work flows at AMTF are well established

Gradients in average above specification (almost 300 cavities tested)
- Average usable gradient after delivery (26.8 ± 7.1) MV/m
- 2/3 of cavities can be used w/o further treatment
- 1/3 is getting additional treatment. -> usable grad. increased to (29.6 ± 5.1) MV/m

Re-treatment gives significant improvement
since ~100 additional treatments / tests for initial gradients < 20MV/m give a projected energy gain of approx. 1300 MeV

Vertical testing incl. re-treatment & re-testing can be finished in time with realistic assumptions based on experience gained so far

Cavities up to XM14 are available for module assembly at CEA Saclay
Cavities (Ready for Transport to IRFU)
100 s.c. Modules for the European XFEL

2-Phase Line (Service Pipe)
Needs and Gets Systematic Repair Work

X-ray to certify longitudinal weld

standard intersection
seamless tube
RF Power Couplers

- Ramp-up of RF power coupler production at Thales / RI needed more time than assumed.
- The problem was the copper plating which requires perfect cleanliness of stainless steel surfaces.
- Reproducibility of copper plating remains challenging.
- In general excellent quality control is required to reject bad parts early during production.
Coupler Pairs Installation in the RF Test Stands
RF Power Coupler Delivery Status as of 4/2014

Deliveries from RI to LAL (2014)

- Ramp up phase
- Production phase
- Nominal rate

Deliveries from LAL to IRFU

- Ramp up phase
- Production phase
- Nominal rate

XM15
Cold Magnets

- 80 (of 100) magnets at DESY
- 67 cold tested
- 48 copper plated
- 20 BQU assembled
- 10 BQU’s shipped
Cavity String Assembly at CEA Saclay / Irfu

- see also next presentation WEIB04 given by F. Chastel (ALSYOM)
Accelerator Cavity String Assembly at Irfu (XM4)
String / Cold Mass Marriage (XM3 & XM4)
RF Power Coupler Assembly
Transport Caps / Final Checks / Shipment
Module Assembly – Buffers are Filled

- string and module assembly relies on sufficiently filled buffers for all parts
- at present parts available at CEA for at least the next 4 modules
  - Cavities
  - Couplers
  - BQU
  - Vacuum parts (bellows / gate valves)
  - Cryostats
  - Magnetic shielding
- transportation boxes and parts-in-circulation are an issue; quick return is a must
Q2/2014 being a decisive quarter

XM5
XM10
XM20

Re-open AMA discussion
Accelerated Module Assembly
Module Transport (XM1 arriving at DESY)
XM-2, XM-1, XM1, XM2, XM3 and XM4 at AMTF
first results: XM-2, XM-1 and XM1 are all above XFEL specs. of 23.6 MV/m

some non-conformities exist but lead to final improvements of series production; feedback to CEA / Irfu
**SRF Experience**

- Major key-player already working together in the TESLA linear collider R&D phase joined the European XFEL in an early phase.

- DESY has the role as *coordinator* of the accelerator complex including the superconducting linac. *At the same time large in-kind contributions* in the field of SRF technology are coming from DESY.

- Work packages contributing to the cold linac are in all cases co-led by a DESY expert and a team leader from the institutes contributing. Integration into the linac installation and infrastructure is a DESY task.

- The European XFEL clearly profits from the *long-time experience* of DESY in SRF technology, and from the history in building and operating large scale accelerator facilities.
Industrial Contracts

- Large series production in industry requires pre-qualification.
- While in some cases vendors were qualified already during the TESLA R&D phase, in some other areas a careful multistep qualification was done.

- There was a strong effort to always have at least two qualified vendors, and where possible the overall production was split accordingly.

- After contract award a continuous close cooperation with vendors is needed. Many of the used components remain challenging, and non-conformities can be reduced only in fruitful discussions. SRF technology does not allow real compromises, i.e. problems have to be smoothened out in a common effort.
In-kind Contributions

- The European XFEL is built based on in-kind contributions. The project includes technology transfer between the different institutes and also industry. In such a model the coordination effort should not be underestimated. The original budget estimate needs to take care of this.

- Difficult to handle are also the duties defined by dependencies, e.g. in the supply chain. In a technically ambitious project the responsibilities in terms of work sharing may be clear but in case of sudden and unexpected technical problems the collaborative spirit is needed and of utmost importance. Discussion of legal constraints is often of no avail, even if necessary.

- Coordination and integration of in-kind contributions requires not only additional resources but also relies on the possibilities of a strong laboratory. Expecting turn-key systems is an incorrect approach. Both partner, the receiving party but also the in-kind contributor need expertise and excellent communication skills. A well-developed team spirit is of large benefit.
The superconducting linac of the European XFEL can only be built due to the great collaborative effort accompanied by an immense team spirit of the involved partners.

Thank you!!!