VISIT TO DESY

8 & 9 September 2009

Meeting notes : R. Garoby, F. Gerigk, S. Calatroni, V. Parma, E. Ciapala

V. Parma (organizer), Thomas Hott (local host) +
Stefan Choroba, Wolf Dietrich Moeller, Bernd Petersen, Stephan Simrock, Elmar Vogel, Hans Weise (DESY) +
S. Calatroni, O. Capatina, E. Ciapala, R. Garoby, F. Gerigk, S. Weisz (CERN)

Purpose : learn about SRF technology from TESLA, ILC and XFEL.

Agenda: **Tuesday 08 September 2009**

12:30	**Welcome** (10')	
12:40	**SPL Project Introduction** (15')	N.N.
13:00	**XFEL Linac Layout & Operations Parameter** (15')	Hans Weise
13:25	**Cavity production** (15')	Waldemar Singer
13:50	**Cavity Auxiliary Devices –> Power Couplers, HOM Couplers, Tuners** (15')	Wolf-Dietrich Moeller
14:15	**Cryomodule assembly and test** (15')	Bernd Petersen
14:40	**Cryogenics System –> Layout, operation modes, incident scenarios & safety measures** (15')	Bernd Petersen
15:05	Coffee (15')	

15:20	**RF System – Modulators, Klystrons, Pulse Transformers, Wave Guides,** (15')	Stefan Choroba
15:45	**LLRF System** (15')	Stefan Simrock

1) Introduction XFEL – T. Hott

XFEL data:
- 2.1 km long 5.3 m diameter + 3 km beam lines with 5 tunnels 4.5 m diameter.
- 2 straights with a slight angle at the end of the accelerator, laser-straight tunnel => small slope ~ 30 m below ground.
- Klystrons in the tunnel every ~ 100m.
- Suspended cryomodule.
- Pulsed cables under the floor. 1.5 km long Other cables are on the side wall.

Two injectors for maximum availability
Produces light pulses at 10-50 fs

Planning: Start of construction at the beginning of 2009. End in 2012. Start of Physics commissioning in 2015

Facility for physics: 10^3 shorter pulse than usual with 10^{10} the brightness of best synchrotron.

DESY: 1400 employees (including post-docs + visiting scientists).
4 departments (1 for Accelerators).
XFEL today: ~ 120 FTE/year. Will go up to 450
PETRA-3 modification and FLASH are still mobilizing a significant number of staff.

2) Introduction on the SPL

3) XFEL – H. Weise

Accelerator consortium coordinated by DESY.
XFEL GmbH is a separate entity, which is based on European rules and which is independent of DESY.
Around 50% of the accelerator (~500 M€) in-kind contributions (DESY itself providing many).
Work Packages for pieces of equipment.
Accelerator Module (12.2 m) is based on experience from TESLA/ILC/…
Will build 3 prototypes from 3 companies (100 in total).
Cryomodules will be assembled in Saclay and shipped to DESY where they will be high power tested.
Applying European rules for Call for Tenders.
Chinese built cryomodule delivered.

Work in CEA will be done by industry at Saclay, under CEA supervision.
Production rate: 1 module per week. 20 days for assembling one module. Infrastructure is in construction.
Test transported a full module between Saclay and Hamburg and found some troubles which will be resolved.

No conditioning or processing (Helium, HPP) after final assembly "If there is field emission after assembly, you have to live with it" (W.D. Moeller).

Recently issued final specifications for mechanical fabrication and cavity treatment.
So far the final treatment for all cavities was always done at DESY. Last year an EP facility was installed at ACCEL and first cavities were treated there. For the series production the complete chemical treatment will be done by industry.

Main companies for building cavities: ZANON and Research Instruments (ACCEL).
These companies will be provided by DESY-made measurement devices (eddy currents scan, optical inspection, RF measurements, tuning of dumbbells and of full cavities ...).
Needed 30 pre-series cavities. Niobium procurement took ~ 1 year.
Units of 4 cavities will be sent to DESY and vertically tested (in their He tank) 4 by 4. In "AMTF" Accelerator Module Test Facility
Gradient & field emission (as measured externally from X-rays) are specified. Then they will be sent to Saclay where the bad ones will be discarded and returned.
The gradient selected is compatible with 90 % production yield. Expect ~ 20 MV/m Freedom is left to the companies to choose either EP or BCP (rough polishing is done by EP)

RF power coupler is from LAL Orsay. Conditioning will be at Orsay.
Detailed assembly and test procedures prepared for the tuner.Installation into the tunnel will be with the waveguide-system already mounted on the modules.
Still to develop is an automated slow flow venting system for cryomodules in the tunnel.
The injector is ~ copy of FLASH Linac.

Magnets with resistive conduction cooled leads.

A tunnel mock-up has been constructed to test installation procedures.

Main difference with previous projects: much more coordination to meet safety rules (Pressure vessel tests, ...), CE certifications + complexity of working with non-European partners.

Offers to host CERN people for a significant period of time to help learn engineering practice.

4) RF system – S. Choroba

XFEL will have 800 cavities - 120 kW/cavity - 23.6 MV/m average gradient.
Power needs: 3.9 MW for 32 cavities
5.2 MW RF source (10 % loss + 15 % reserve)
10 Hz rate (up to 30 Hz but limited by average RF power of klystron 250 kW).

Modulator Hall ---- Accelerator tunnel (klystrons + pulse transformer) linked by 10 kV pulsed cables.
Tunnel: klystrons on the floor + suspended cryomodules.
~30 modulators in a single hall (football range size).
3 prototype 10 MW MBKs developed by THALES, TOSHIBA and CPI.
Fit for tunnel installation: 2.9m long, 0.6 m diameter.
e.g. TOSHIBA E3736H – 10 MW at 118.8 kV + 129.5 A
it was stressed that prototype klystrons must be tested at full duty cycle (which is not always possible at the manufacturer). DESY discovered problems when going beyond the duty cycle that was tested at the factory (Thales).
Only vertical klystrons tested so far, horizontal needed in machine
Bandwidth ~ 2 MHz. Total weight ~ 3 tons (including pulse transformer).
Hoping for a price < 0.5 MEuros/unit.
Don't expect more than 60% efficiency from klystrons
Voltage stability +- 0.5% required to achieve the required phase stability (0.01 deg).
Simple bouncer modulator provides this without problem
The LLRF needs this stability to get the required 0.01 degree RF precision & reproducibilty
Pulse transformer is 2.6 m long x 1.4 m high.
1.57 ms flat top at 120 kV with bouncer to get flatness. IGCT switches.
Alternative solutions: PSM solution by Thomson Multimedia which provides regulation within the pulse + failure tolerance.
Same price and volume than the bouncer type.
0.5 – 1 MEuros price range. Much more costly than the klystron
Pulse transmission via cables tested successfully over the distance needed

RF distribution:
- 32 cavities / klystron (8 cavities/cryomodule)
- asymmetric shunt tees + 1 splitter for 2 cavities.
- 1 circulator for each cavity.
- 1 phase shifter (mechanical with remote control) for each cavity. (May manage to do without).
- Klystrons are 10 MW able, but the need at the start is for 5.2 MW! Hidden agenda is to one day get 35 MV/m cavities.
- Adjustable RF couplers (Qext: 1e6 - 1e7) to allow for very different modes of operation (remotely controlled).

5) LLRF of XFEL – S. Simrock

Requirements: phase stability <0.01 degrees (20 fs) and better at some places of the injector (everything included). Of the order of 0.1 degree along the accelerator length.
100 fs can be achieved with coax transmission, 10 fs with fibre
… high power phase shifters / cavity + variable couplers.
Hardware ATCA-based. Installed in the accelerator tunnel, in a shielding enclosure. Each rack has its own temperature control.
Closed loop bandwidth is up to 60 kHz. Gain 300
'Degraded' mode of operation available if problems, feedforward only, no RF feedback
Klystron characteristics is corrected in open loop (no klystron loop is felt necessary, based on FLASH experience).

6) Cryomodule assembly and test – Bernd Petersen

Using Titanium and Niobium, because soldering technology is well mastered.
Niobium quality of todays market is very good. Only 5-10% of the material is rejected after careful scanning of incoming sheet (specified)
Discussion on heat processing. 800C is chosen for hydrogen degassing. Higher temperatures (1400C) for Nb purification are no longer needed with today's quality of the raw niobium…
Company put a lot of efforts in providing pure material that helps avoid high temperature treatment and provide good welding on the equator.
NbTi flanges are used, they also go in the furnace at 800C. Flat flanges with Al diamond seal, commercial. The titanium He tank is welded afterwards
Copper plated stainless steel bellows in-between cavities. Aluminium vacuum joints.

2 industrial studies have been made and published on the assembly of full cryo-modules (BABCOCK, ACCEL)
Details about assembly are available in 2 industrial studies on the XFEL site.
Basic design is based on TESLA technology.
Cavities are filled with He-2 from 2 phase tube. Gas from each cavity is returned by large gas return pipe. Tube size limits warm-up speed. 1 week cool down / warm up.
Cavities are fixed with Invar rods to avoid movements during temperature changes. Cavities are aligned warm. It was tested with a wire-system that the transverse positions remain stable during cooldown. For the series production there will be no longer the provisions for a wire measurement.
According to the pressure vessel code cavities have to be tested at 6 bar. This was done without seeing any plastic deformation. However, the cavity was slightly detuned afterwords.
3 posts hold the He return pipe.
1 manual (cold) valve at each end of a cryomodule. No valve between cavities.
Assembly of cavity string in clean room.is with bolts and screws, including cold part of couplers.
Then string is closed and moved out of clean room and assembled onto the support pipe.
Magnetic shield is then installed.
RF tuning of cavity cells is done at warm in the companies building the cavities.
" Q-disease" sometimes happens because of H_2 in solution in the niobium, which precipitates into hydrides (which are normal conducting) during cooldown if process is slow (precipitation is diffusion dominated). Often avoided by fast cooling from 150 K down to 4 K. Not possible at XFEL, but felt not necessary because of the quality of nowadays Nb and a 800 C heat treatment of the cavities. Q-disease can be checked by keeping a cavity at 100K for several hours. If the resulting Q is lower the cavity has Q-disease.
RF couplers have 2 windows. No contamination during assembly in cryomodule.
Alignment tolerance for quads: +-0.3 mm and +-3 mrad. for cavities: +-0.5 mm

Building an Accelerator Module Test Facility capable to exercise 3 modules simultaneously.
Duration of test for 1 module: 12 days +-3.

7) Cryogenics – Bernd Petersen

Design pressure for the cavities (He tanks) is 4 bars. Even tested with a safety margin of 1.4 giving no plastic deformation.

It is a lot of pain to exchange a cryomodule. 2 weeks for warm-up … for total of 6 weeks.
No spares but 8 extra-cryomodules installed in the beam path and nominally not powered.
The only difficulties where found in some of the first modules: tuners (wrongly operated), He feed throughs, and leaks between beam pipe and insulation vacuum. In later modules these problems did no longer occur.
Cryogenics tasks: 816 cavities @ 1.3 GHz, 40 cavities @ 3.9 GHz, 92 cryomodules in operation, 8 idle.
Operation schedule of 2-3 years without warm-up. Availability > 99%.
All cryo-pipes are within the cryomodule.
String connection box between 12 cryomodules (about 150 m) with vacuum barrier.
Heat < 20 W/cryomodule.
Pressure differences in the vapour return line will be greater in SPL and may limit the cryomodule length
Feedthroughs at the location of each magnet.
Checked effect of different incident scenarios on a full size cryomodule.
Only degradation obtained with catastrophic loss of cavity/beam vacuum to ambient air.
Propagation of air through the beam tube takes ~ 4 s, which allows for protection of the other modules by a valve.
=> layout of safety valves (2K circuit: 2 DN150 SVs at both ends of the linac - 5K/8K/2.2 K safety valves at each string connection box - 40/80 K safety valves at both linac ends).

Maximum Credible Incident: much less stored energy than in LHC => LHC-like event very unlikely. But consequences could be much more severe because of suspension to the ceiling. => installed much more release valves.

GRP limits the cool down and warm up time (due to alignment).
Cavities dressed supplied by manufacturers. Mechanical Alignment reference w.r.t. electrical axis is made in industry. Then references transfer to cavities flanges. These are the referentials for alignment during assembly of string to GRP.
Cool-down (warm up) time: 1 week.
Alignment during cool-down warm up changes.
Quad:+or-0.3mm precision.cavity quite less.
Cryomodule cold testing: ~10days each.

Breaks: first protos helium leaks: weld Ti vessel, or 2-phase welding, no leak at operation. Cold tuner electronics feedthrough broken.

Design pressure 4 bars, safety valves 2 bars absolute. 1.4x4 is the test pressure.
Replacement of cryomodule is not foreseen during an operation run. But in case: 2 weeks warm up, intervention, then 1 week for cool down. 8 built-in "spare" cryomodules out of 100 cryomodules! No real spares for the moment.

1 cryoplant.9-10 cryo strings for a total of 1.7 km length. Vacuum barriers at each sting connection box. Each SCB is about 3 m long. 150m sectorisation of insulation vacuum. Helium supply
Low pressure is 31mbar and .K
Up to 20 W per cryomodule only then wavy behavior expected.
Reused one existing Hera 4.5 K plant upgraded with 2K cold box. Similar to one LHC box, but 2 refrigerators used in parallel.

Vacuum Valves foreseen every 150 m (cell) at connection boxes but still under discussion. Then fast warm valves in the CWT zones. MCI being analysed by WUT Poland.
Cooldown pressure 1.3-1.4 bars abs. not to open safety valves at 4 bars.
Note: stratification of helium vapors in GRP gives visible alignment modifications.

Beam vacuum pumping ports at every cryomodule, at the bellows-cryostats interconnections. No ion pumps
TM pumps for insulation vacuum

8) RF components – Wolf Dietrich Moeller

High power coupler:
- average power: 1.9 kW
- High power processing 1 MW at reduced pulse length 1.3 mS 2 Hz. Done two at a time,
- Looking at design of RF processing system.- Variable coupling (adjustable from the outside of the module) Qext 1e6 – 1e7.
- Double window system: 1 cold + 1 warm.
- Horizontal.
- Bias on inner conductor against multipacting.
- Cylindrical ceramics with TiN coating.
- S.steel parts including bellows are copper plated (galvanic)
- Region between the two ceramics pumped by SPI plus sublimation pump

Modified at Cornell to operate at higher average power with more cooling on the inner conductor and other minor changes.
Power Coupler was operated in 1 case up to 600 kW because of detuning. No problem recorded.
Beam line HOM absorber: ceramic absorber cooled at 70 K. 1 at the end of each cryomodule.
Only plain bellows, without RF screen, even along the beam pipe (between cavities and between modules). Bellows are nevertheless a critical part of design, and all copper plated

HOM coupler couples to the lower frequency range. Considering improved feedthroughs from JLab with better thermal conductivity. Feature due to the presence of the notch filter which must be superconducting. One per cryomodule
Tuner: The Saclay type tuner was adopted (not the blade tuner, which is foreseen for the ILC), resolution: 1 Hz/step - 800 kHZ slow range – 1 kHz fast range.
Mechanical lever arm design. With stepping motor and piezo elements.
Piezo stroke at cold is 10-20 % of room temperature.
Important: If the step motor of the tuner fails and the cavity needs to be detuned because of cavity problems, then the machine has to be stopped for replacement of the cryomodule.

9) 3rd harmonic RF system @ 3.9 GHz – E. Vogel

Bunch compressor transforms 50 A peak current into 5 kA! Linearization of time vs energy dependency with 3rd harmonic.
RF couplers are on alternating sides of the beam pipe. ~ scaled copy of 1.3 GHz device.
Also used in FLASH but with less voltage (19 MV instead of 40 MV).
Alignment +-0.5 mm to keep transverse blow-up at ~ 5%.
INFN will build the cavities for XFEL.
Cryogenic pipes will be flanged.

Agenda : **Wednesday 09 September 2009**

09:00	**Technical Coordination –> Integration of the XFEL Facility** (15')	Thomas Hott
09:30	**Information Management** (15')	Lars Hagge
10:30	**Visit to CMTB (Cryomodule Test Bench) and FLASH hall** (1h30')	
12:00	Lunch (1h00')	

1) XFEL technical coordination - Thomas Hott

Role: technical coordinator.
Total budget 1000 MEuros – German contribution 560 MEuros.
Mission of Technical Coordination: coordinate and supervise the overall systems integration into the final facility (including Civil Engineering).
Need to define: what shall be built, by who and how (quality…).
Need for clear links between TC and WPs. Change management is a responsibility of the TC.
Presently defining a Work Breakdown Structure.
In a transition phase. In the process of organizing the project, which is not along the usual DESY practice.
Systems integration is based on 4 pillars:
- (accelerator) section coordination,
- 3D/CAD integration
- Installation workflow coordination,
(e.g. infrastructure cabling and piping will take 1 year…)
Machine installation will take 99 weeks after infrastructure installation.
- Reviewing: Conceptual Design Review, Design Review, PRR followed by fabrication/tendering.

2) Information Management – Lars Hagge

Project Life-cycle Management. Based on "Teamcenter Enterprise".
Set-up and resource profile very similar to what happens in industry for unique products.
Using EDMS platform to store/manage information for lifespan of 30++ years.
Project phase: Prototyping/industrialization with very distributed project team.
Need for managing complexity of collaboration, coordination, communication…
Building unique products: no reference processes.
Collaboration partners rely on their own design and simulation environments. Contribute to PLM on casual basis.
Users are involved in several projects in different roles.
User acceptance is key to success.
Discussion: quality assurance is not specified at the level of DESY.

Civil Engineering: 3 construction sites.
Try to convince contributors to immediately use the tool.
Standard tool for commenting/correcting is Adobe Acrobat Professional.
English is enforced, except for Civil Engineering because of German Law and because of the implication of local workers.
Project follow-up is done with MS-Project Professional.
3D CAD QA team checks consistency of the documents/drawings received, look for conflicts and requests follow-up…

Discussion: standardization… Know it is mandatory. Expect it to happen as part of the review process before tendering.

Representing physical parts: e.g. cavity (efficient/ clear web interface).
Next challenge: extension to a full cryomodule.

Comment: ~ CERN MTF process.

Process industrialization.
Set of documents/instructions for every item.

Visit to CMTB FLASH hall and Tunnel mock-up
- Cavities tuned before He tank fitted.
- Warm cavity measurement & adjustment gives the correct frequency when cold
- Heat treatment has no effect on frequency
- No frequency drifts in early operation, i.e. after initial cool-down warm-up cycles