

Elettra Booster Power Converters Refurbishment

or

"What do we learn with the Elettra Booster Power Converters Design?"

or

"A Year-Long Challenge"

R. Visintini

- ✓ Background
- ✓ Status
- ✓ Refurbishing Program
- ✓ The Question

Background: The Booster Power Converters

Call for Tender:

- Five Companies (OCEM, EEI, Danfysik, Jema, Kempower)
- Detailed Technical Specifications & Statement of Compliance
- *Kempower's Offer: best Technical Proposal vs. Price*

	Dipoles	Quad's	Sext's	Unit
Digital Control and Interface	PSI's DSP/ADC system provided by ST (DLS)			
# of Power Converters	2	2	2	
Output Voltage	±1000	±400	±35 / ±70	Vpk
Output Current Range	15 - 800	5 - 400	±35 / ±70	A
Instantaneous Peak Power	600 / -400	115 / -50	1.2 / 4	kVA
Max. Op. Frequency	3.125			Hz
Current Ripple	±15			ppm
Current Stability (<8hrs)				
Load Nom. Resistance	260	360 / 310	700	mOhm
Load Nom. Inductance	112	81 / 54	42	mH

Background: Kempower's Credentials



DEVELOPMENT, TEST AND LARGE PRODUCTION OF SOFT SWITCHING HIGH CURRENT POWER CONVERTERS FOR PARTICLE ACCELERATORS

F Bordry, V Montabonnet, D Nisbet,
European Organisation for Nuclear Research (CERN)
1211 Geneva 23,
Geneva, Switzerland
Tel.: +41 / (22) – 767.43.97.
Fax: +41 / (22) – 767.53.00.
E-Mail: david.nisbet@cern.ch
URL: <http://www.cern.ch/>

P Korhonen, P Turunen, H Volotinen,
Kempower Oy,
Hennalankatu 39, PL 13, FIN-15801,
Lahti, Finland
Tel.: +358 / (0)3 – 89.911.
Fax: +358 / (0)3 – 89.94.17.
E-Mail: petri.korhonen@kempower.fi
URL: <http://www.kempower.fi>

Keywords

«High frequency power converter», «Switched-mode power supply», «DC power supply», «Parallel operation», «ZVS converters», «Free wheel diode (FWD)», «Three-phase system»

Abstract

The Large Hadron Collider (LHC) is the next particle accelerator being constructed on the CERN site. The 27km long accelerator requires many high current (multi-kA) power converters to supply the superconducting magnets. This paper describes the development of a modular high current power converter, capable of supplying up to [8kA, 8V] using several current sources of [2kA, 8V] in parallel. Production aspects and test results of 200 power converters are presented and analysed.

CERN COURIER

Feb 8, 2006
Faces and Places

Suppliers win Golden Hadrons

The fourth CERN Golden Hadron awards saw seven suppliers for the Large Hadron Collider (LHC) receive recognition for their high quality of work, respect for delivery dates, flexibility, and adaptability to the demanding working conditions of the project.

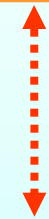


The awards went to Kemppe-Kempower (Finland), Metso Powdermet (Finland), Transtechnik (Germany), Babcock Noell Nuclear (Germany), Iniziative Industriali (Italy), ZTS VUVU Kozisek (Slovakia), and Jehier (France).

A leading manufacturer of arc-welding equipment, Kemppe-Kempower produced the only workable prototype of the high-current and high-precision power converter for the LHC, when faced with competition in 2002 from two other suppliers. Subsequently, the Finnish firm received the contract for pre-series and series delivery, and by July 2005, 82 power converters had been delivered and accepted, constituting 42% of the total production.



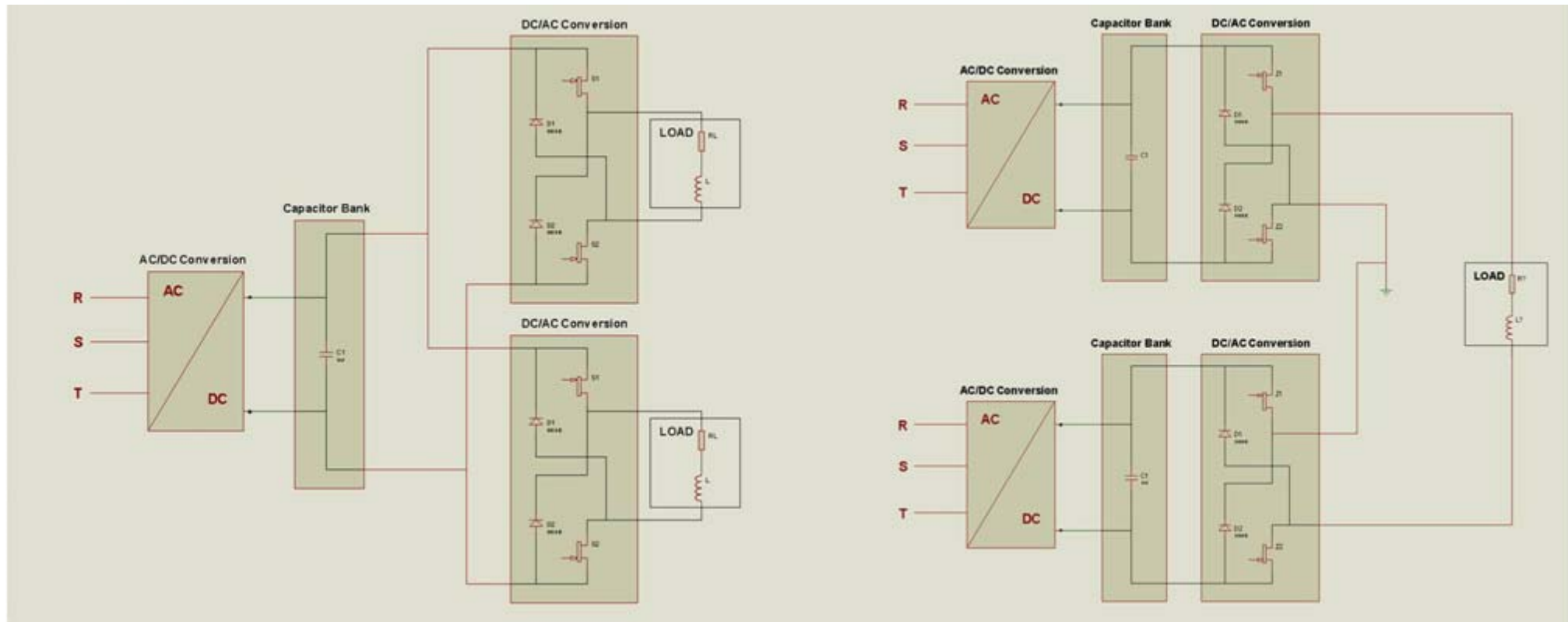
Background: Lahti vs. Trieste



1870 km



Background: PCU General Structure (original)



Quadropole PCs (2 units in the same cabinet)

Dipole PC (2 units in series in each cabinet)

Key Features:

- Highly Modular Design
- Same modules for both types
- N+1 Redundancy in all sections (AC/DC, DC-Link Caps, DC/AC)

Background: Factory Tests

First Difficulties:

- Delays
- Faults during factory tests
- Insufficient AC power available at factory for full output tests
- Too "weak" loads
- Booster Project Time Schedule

Consequences:

- Factory tests repeated three times
- Tests on mostly resistive loads
- The 2Q operations could not be fully verified
- Decision to ship the Pc to Trieste to stay within the limits of the time schedule



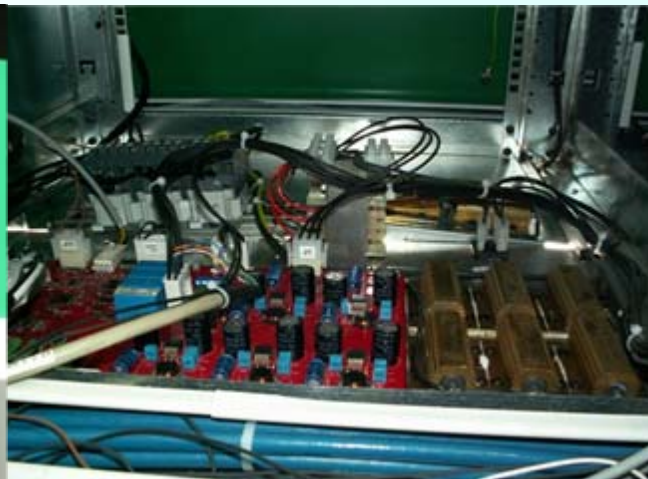
Background: June 22nd: Arrival at Trieste...

...damaged due to transportation!

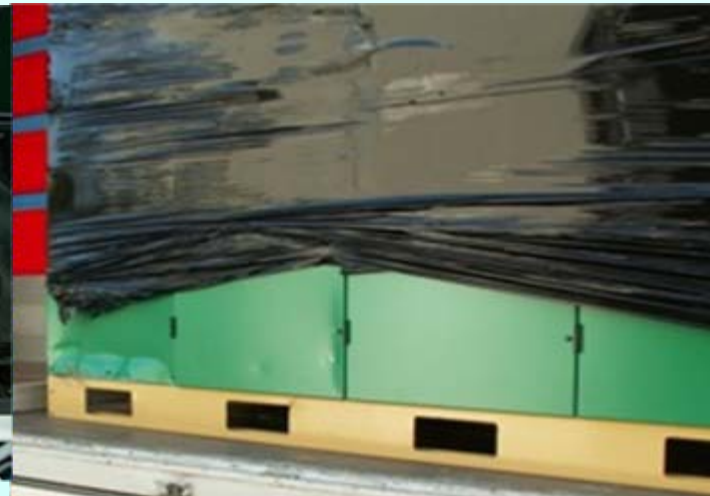
- A dedicated shipping was not chosen
- Insufficient protection for a multiple carrier shipping - the cabinets were loaded and unloaded on trucks at least three times.
- Damages both outside and inside the cabinets



Broken CB Handle



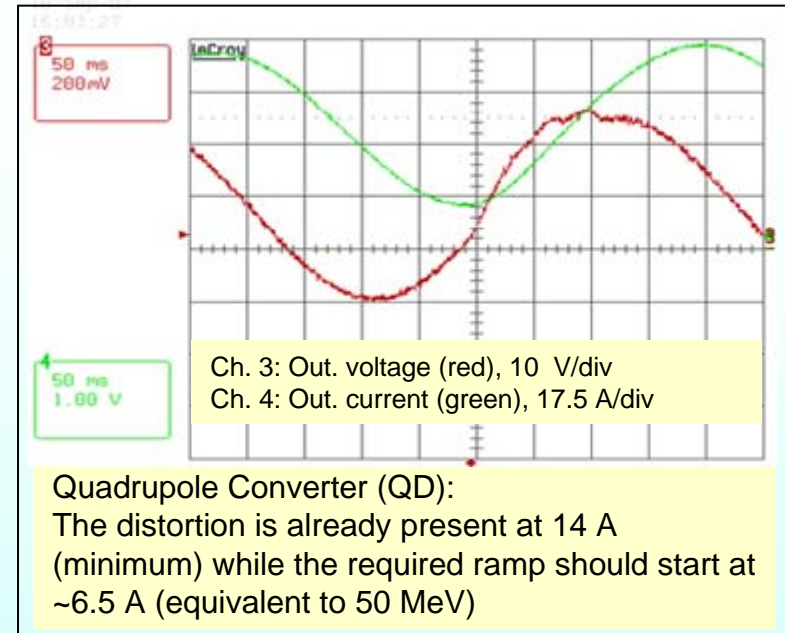
Bottom plates lifted up



Bumps & scratches on sides

"Every Solution brings new problems"

- Shipping damages repair and pre-start up tests on resistive load in July. Tests on actual loads in August.
- Main hardware troubles:
 - Output voltage and current distortion when ramping (hw modification: 2Q → 4Q);
 - High ripple content in the output current (also after improving the filtering);
 - EM noise and its consequences on operating the PCs (increasing with the peak power)
 - Not optimal charging of the DC-Link
 - Overheating of the output filter chokes
 - Sextupole converters heavily damaged during stability tests in DC.
- Factory tests could not be repeated
- The quadrupole converters could be operated together at nominal values (3 Hz, "2.5 GeV" currents)
- Dipoles operated at "2.0 GeV" current, "single 3 Hz Pulse per second" mode



"Non Hardware" Actions taken

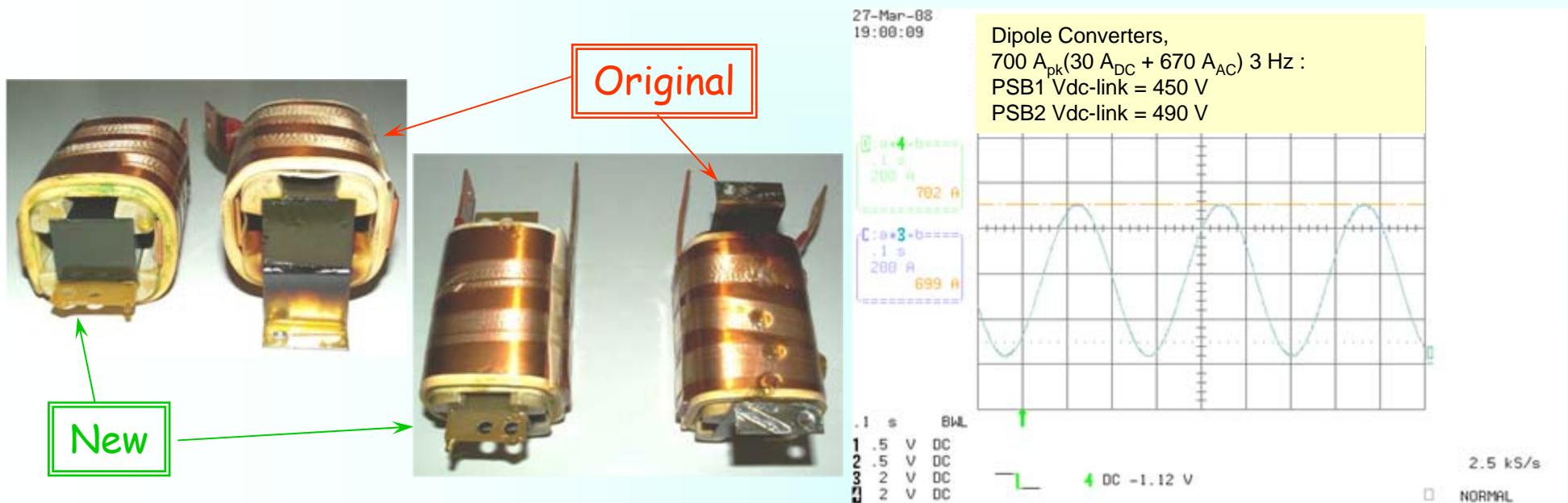
- Advice, suggestions and help from colleagues of other Laboratories (PSI, DLS, DESY, ALS, SLAC)
- Internal team for addressing the problems in parallel to Kempower
- Power Converters Refurbishment Program from Kempower

End of the "B & SR" commissioning phase (March 3rd, 2008):

- Dipole converters peak current still 2.0 GeV, one "3 Hz Pulse per second" (EM noise and damaged modules)
- Identified additional "*Big Issues*":
 - Control Crate to be redesigned (signal conditioning, noise immunity, length of connections,...)
 - Missing a real self protection of DC/AC power modules (4 modules were severely damaged and sent back to Lahti)
 - DC-Link charging algorithm still not adequate (high variations in the AC input power)
 - New strategies for current ripple reduction have to be found
- **Defined and imposed to Kempower, under their responsibility, a full Power Converters Refurbishing Plan**

Some Results after the 1st Refurbishing Step

- Started in the Holy Week and during the "Easter Shutdown"
- The scheduled actions were completed by Kempower's people according to the time schedule
- **Replaced the output filter chokes: overheating issue is SOLVED**
- **All output modules are in place and also the Dipole Converters CAN operate at 3 Hz up to the "2.5 GeV peak current".**
- Added EMI shielding to the control crates but still problems deriving from induced/picked up EM noise.



BUT...

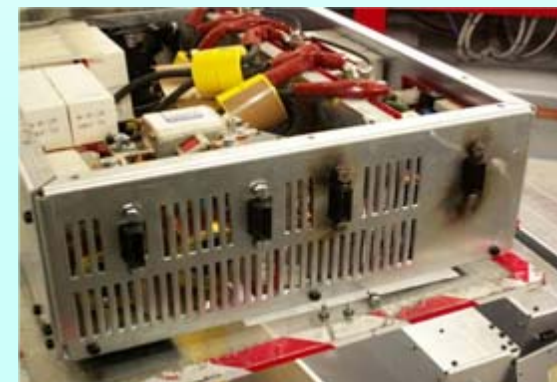
Status - Major Faults on Dipole PC

What has happened

- During normal operations at 2.0 GeV a large number of output modules (a.k.a. DC/AC) on one Dipole Power Converter went in fault (April 17th, morning).
- First attempt to put the PC operational - removing the apparent cause and replacing the broken units - failed: more units damaged.
- Still investigating on the real causes of the failure:
 - ❖ Spurious turn on of IGBTs in the same leg of conducting ones
 - ❖ Wrong PWM pattern due to EM noise that influences the FPGA inside the control cards
 - ❖ ...
- Similar fault occurred again after the (scheduled) intervention of Kempower following the Refurbishing Program

Actions Taken:

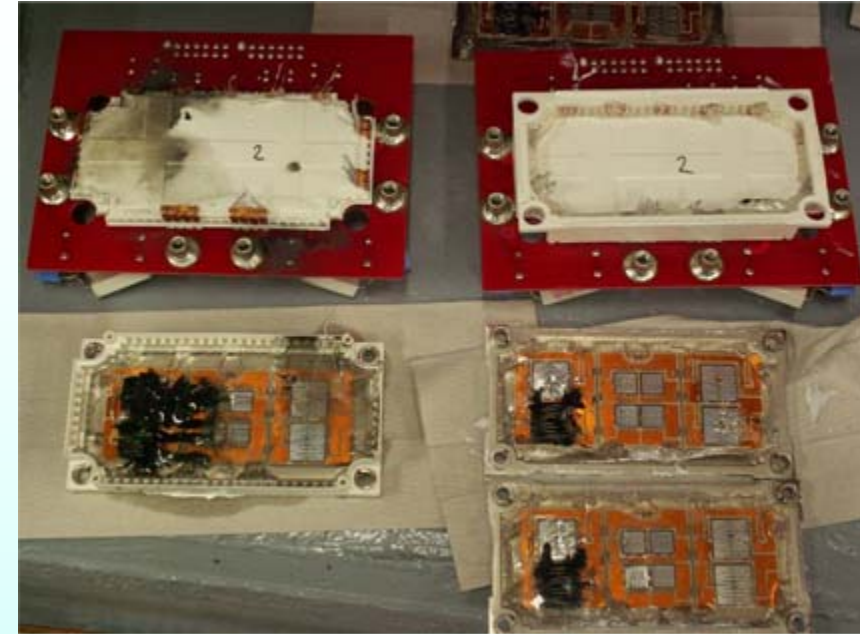
- Moved the magnets' connections to the still working converter and put the loads in series → peak current limited to 1 GeV
- Operate the Booster at 1.0 GeV, trying to inject into the SR and then ramp the SR to the final energy



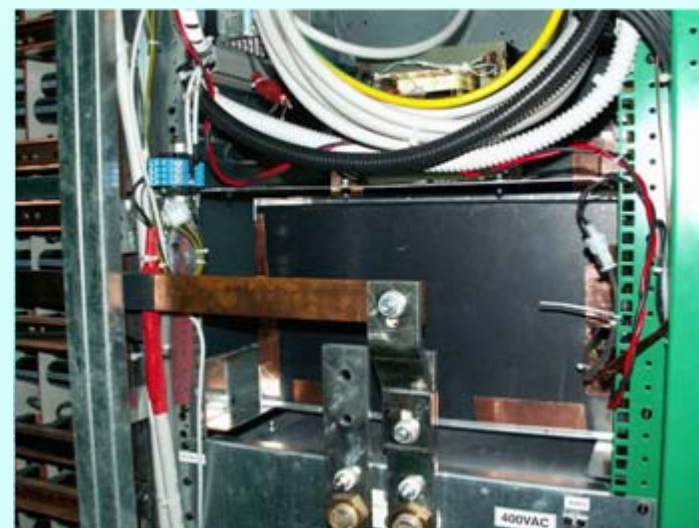
Status - Damages to IGBT modules

DC/AC Unit

- Three IGBT modules (full H bridge, 1200V/150A) in each Unit
- All IGBT modules are dead
- Apparently, the faults tend to occur to the Lower Section in the same Dipole cabinet.



Status - Dipole Cabinets Snapshots



Temporary EMI Shield on the "Common Control Crate"

Status - Quadrupole Cabinet Snapshots



Refurbishing Program: Plan of Activities

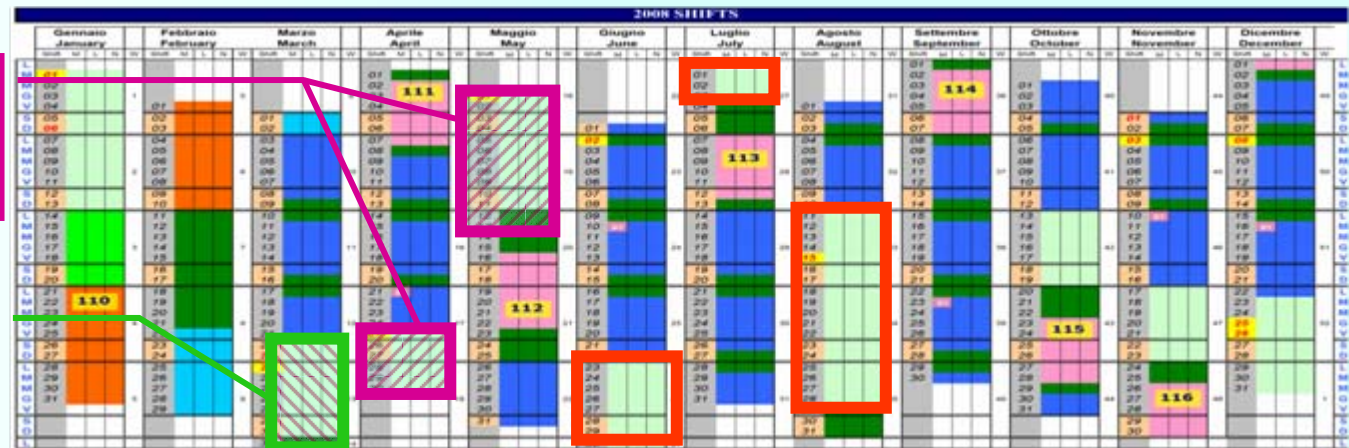
Definition of a Refurbishing Program:

- Defined with Kempower a detailed but not exhaustive program of activities under their responsibility
- Many items (e.g. Control Crates) must be prepared and tested in Lahti before mounting and testing in Trieste
- Almost all activities to be done during the shutdown only → interferences with systems maintenance
- By the end of August the PCs have to be compliant to the Specifications.

KEMPOWER® POWER CONVERTER Intelligent Power Modules REFURBISHING		1 (9)
Petri Korhonen		18 February 2008
POWER CONVERTER REFURBISHING – KEMPOWER'S PROGRAM OF ACTIVITIES		
Contents		
A. GENERAL	.....	2
A.1 Objective	.....	2
B. REFURBISHING ACTIVITIES	.....	2
B.1 General Comments	.....	2
B.2 Known Refurbishing Activities	.....	2
C. TIME SCHEDULE - TENTATIVE	.....	7
C.1 Within 14/03/2008	.....	7
C.2 Within 21/03/2008	.....	7
C.3 Shutdown W13:08 (25/03/2008, Tue – 29/03/2008, Sat, full day)	.....	8
C.4 Shutdown W15:08 – W19:08 (25/04/08-09/05/08)	.....	8
C.5 Shutdown W26:08 – W27:08 (23/06/08-04/07/08)	.....	9
C.6 Shutdown W33:08 – W35:08 (11/05/08-28/05/08)	.....	9

Step 2:
Partially done and not
successful (still 1 PC offline)

Step 1:
Completed in time but not fully
successful (noise issues)



Next (main) steps

"June/July Shutdown" (W26 & W27/08)

- Put the second dipole back into - reliable - operations
- Implement an effective low-level self-protection of the IGBTs inside the output modules to improve the reliability against failure of the driving signals
- Redesign - following the PSI/DLS indications - and install a new version of the "Control Crate" and "Alarm Cards" to improve the noise immunity of critical signals and - consequently - the reliability of the operations

"August Shutdown" (W33, W34 & W35/08)

- Complete any pending activity

Other Examples: "Standard Products"



"Conventional DC Power Converters"

- Less demanding converters were chosen among "standard products" of some companies (Call for Tender in some cases).
- Danfysik System 9000 (25 units):
 - ❖ 6 units were broken at switch on
 - ❖ Factory Tests Results delivered
 - ❖ Found a "quality issue" on the power cards: to be replaced in all → More Refurbishing!
- Delta Electronics - "Off The Shelf":
 - ❖ Notwithstanding the tests on a "test unit", severe remote control problems (Ethernet) were found during operations.
 - ❖ 7 units need firmware update → More Refurbishing!



"What do we learn with the Elettra Booster Power Converters Design?"

- ➔ "They did a great job for me but it is NOT assured they will do as well for you!"
- ➔ "Standard" or "Off the Shelf" products do NOT guarantee success
- ➔ Detailed documentation is NOT sufficient.
- ➔ Inspections at the Factory and subsequent Reports are necessary but NOT sufficient.
- ➔ Simulations are a great tool BUT they are not sufficient.
- ➔ A load with adequate characteristics **MUST** be used for Factory Tests (in case buy or borrow it)!
- ➔ Respecting the Time Schedule of the main Project is important BUT it may lead to unexpected bad surprises.

Many thanks to

The Elettra colleagues (alphabetical order):

Marco Cautero, Denis Molaro, Chris Pappas,
Piergiorgio Tosolini, Maurizio Zaccaria

Colleagues from other Laboratories ("chronological" order):

René Kuenzi (PSI), Robert Rushton (DLS),
Joerg Eckoldt (DESY), Mike Chin (ALS),
Paul Bellomo & Antonio De Lira (SLAC)

Additional Tools to be used



Any suggestion?