SPS TWC 200 MHz

Super Proton Synchrotron

Travelling Wave Cavities

200 MHz

4 x 1.0 MW cw

25 years of experience

SPS TWC 200 MHz

History

25 years of experience :

- Preventive maintenance
- Tetrodes
- Power couplers
- Power loads
- Power converters
- Control
- Infrastructure

What next

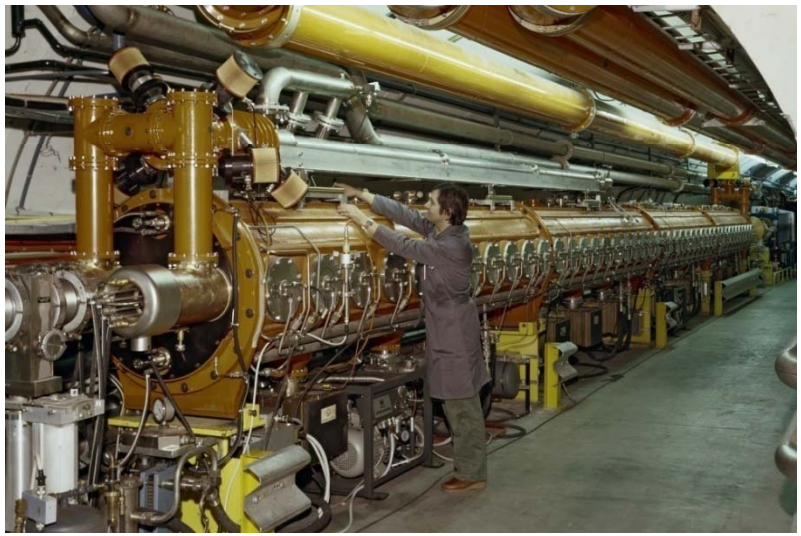
Conclusion

Thanks to all the team
working on these power plants

History

The SPS started up in 1976 with two accelerating cavities. For the new role of the SPS as proton-antiproton collider, a third cavity was installed in 1978 and a forth one in 1979.

Since 1980, there are four cavities operating @ 200 MHz in the SPS.



One of the SPS acceleration cavities (200 MHz, travelling wave structure).

View into a tank of a SPS accelerating RF cavity

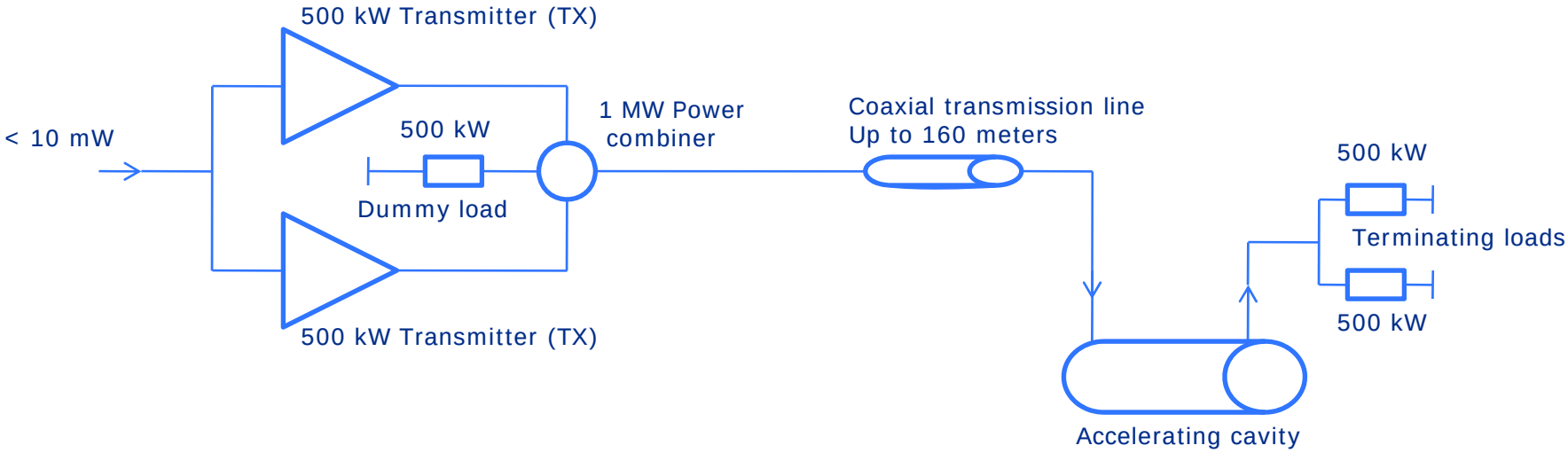
View of a section of an SPS accelerating RF cavity

History

The power amplifiers, using tetrodes were installed in a surface building 160 meters from the cavities.

By end 1980 there were :

- 8 x 500 kW units combined in pairs
- 4 lines, 8 transmitters with :
  - 4 x Siemens : 20 x 135 kW RS 2004
  - 4 x Philips : 72 x 35 kW YL 1530



Configuration of one of the four 200 MHz power plant

History

The first Siemens amplifier plant under construction in 1976

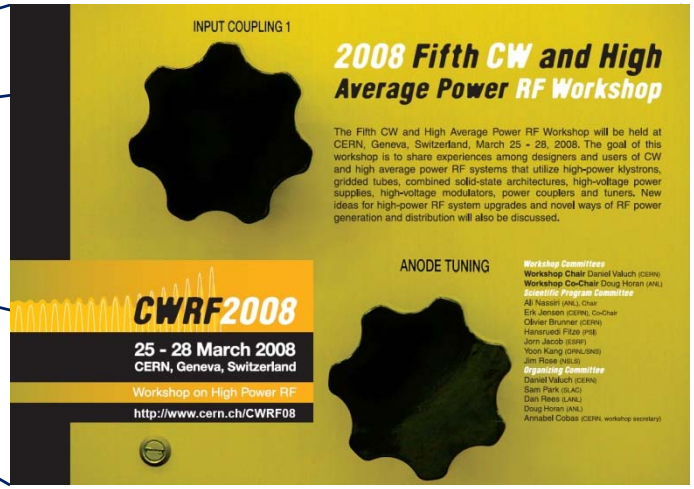
The Siemens amplifier plant as it is since 1980 (28 years ago !)

One of the RS 2004 J power tetrode inside its trolley

The Philips amplifier plant also as it is since 1980 (28 years ago !)

History

The predriver chain :
1 kW tetrode + 10 kW tetrode



The workshop background picture !

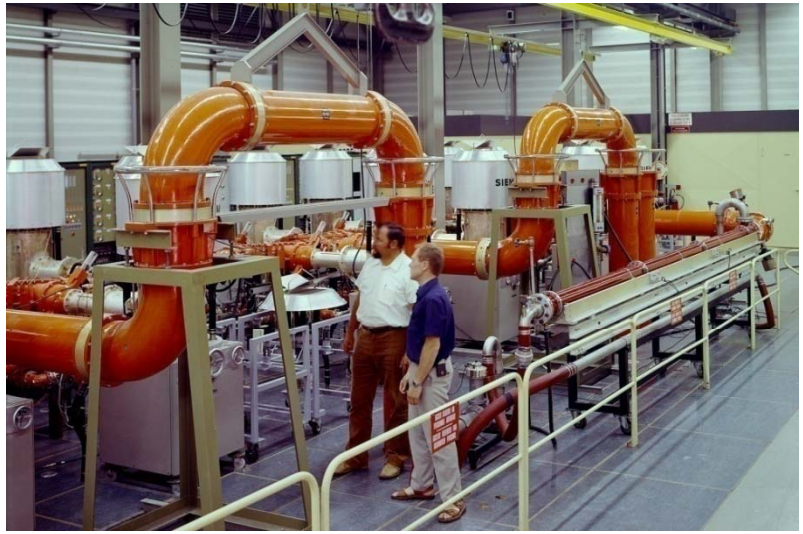
History

We realized some tests last year, and we obtained 750 kW cw per cavity, maximum for the transmission lines, but after 1 hour the whole amplifier was really overheating.

We then made some pulsed tests, with cycle of 10 s on / 10 s off, and with one line, we reached 1.050 MW for 1 hour.

Nevertheless, with the actual machine bandwidth requirements, overheating difficulties, and weak components, our power plants level must be limited to :

- 4 x 750 kW maximum.
- 4 x 600 kW average.



The picture shows the first RF power plant
550 kW cw @ 200 MHz on a matched load
Which has been maintained for 24 hours in 1976.

25 years of experience

As the workshop goal is :

"to share experiences among designers and users of CW and high average power systems"

I sorted out the most significant points we experienced over the last 25 years with these huge number of components.

104	Tetrodes
16	Power couplers
116	Power splitters and combiners
740	Directional couplers and RF detectors
740	Power loads
128	High voltage power converters
54	Blowers or pumps
10'000	Control logic circuits or relays
720	Meters of power coaxial transmission lines
4	Cavities

Preventive maintenance

With a cycle of 4 years, we carry out “preventive” maintenance on the equipment.

we dismount, clean, repair, remount all the components :

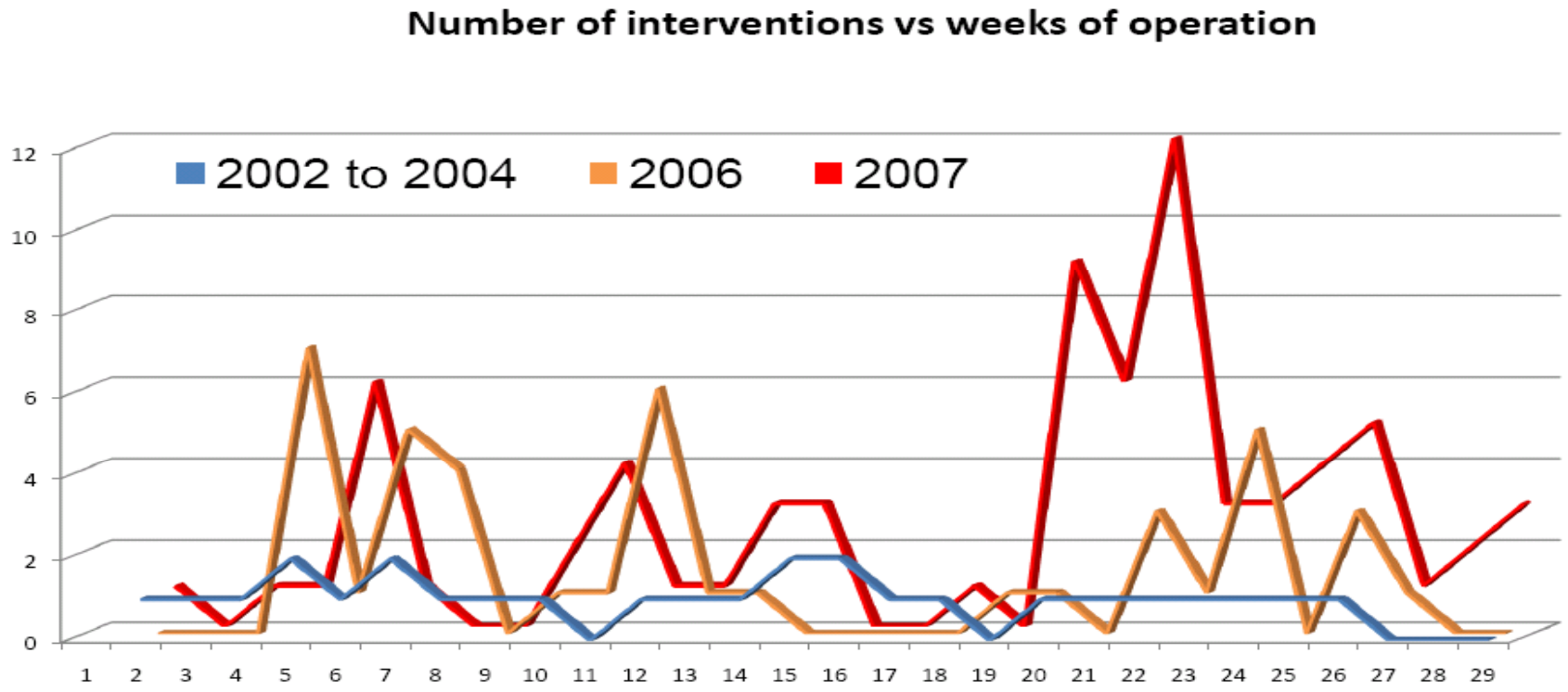
- Amplifiers
- Power supplies
- Pumps and blowers
- Loads
- ….

We do that each year for one Siemens transmitter and for one Philips transmitter.




Annual maintenance of
17 / 68 Philips power amplifier :
dismounting, cleaning, repairing, remounting.

Preventive maintenance



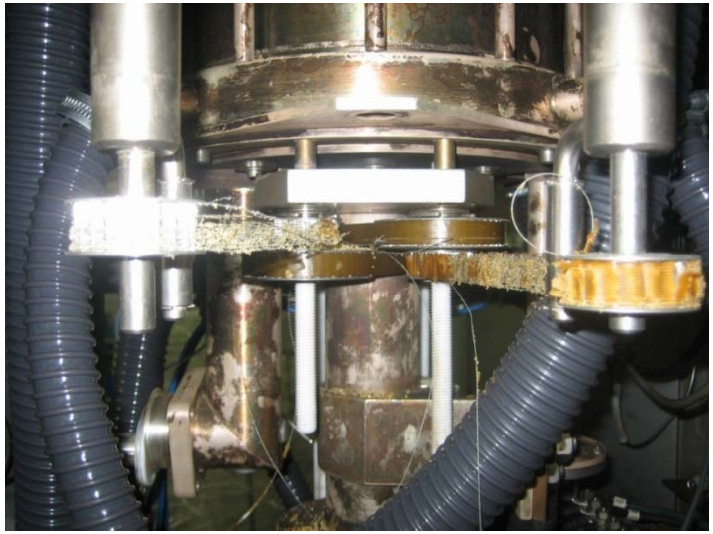
Unfortunately, due to lack of resources and money, we had to reduce this preventive maintenance.

Preventive maintenance

Increase the maintenance cycle of the RS 2004 trolleys :

All belts overheat, and if not changed, they decompose.

The amplifier can no longer be tuned.



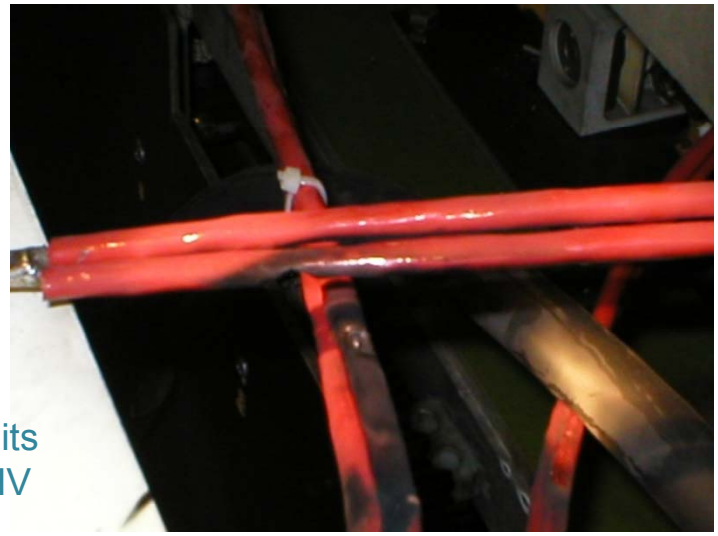
Belts overheated

The “Siemens” trolley

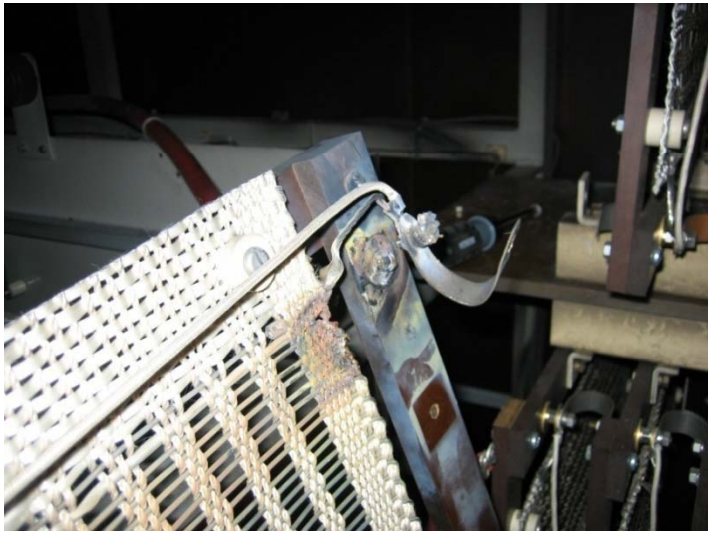
Preventive maintenance

By not cleaning and carefully checking the HV power converters :

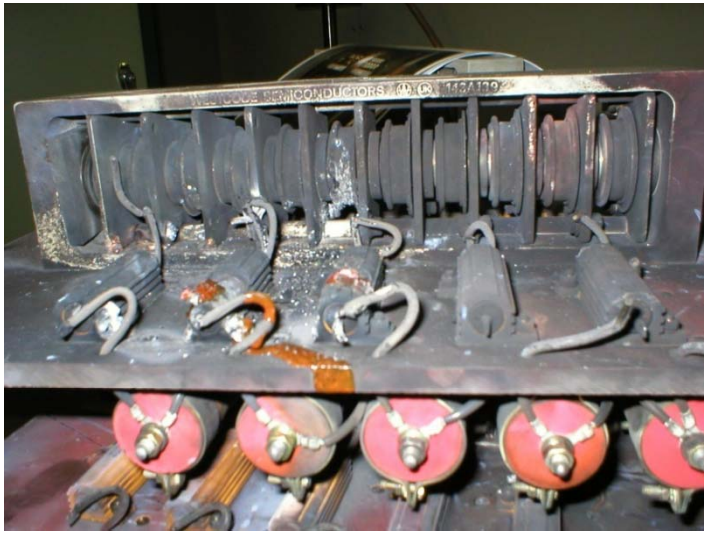
Cables start to deteriorate, and we have some impressive short circuits.



Short-circuits between HV cables



Broken connection on a power resistor



Exploded diodes bridge (10 kV / 120 A)

Preventive maintenance

If preventive maintenance is not done :

- It is a problem for operation.
- But it also increases the risk of important irreversible damage to the equipment.
- And, it increases the danger for the personal.

This crucial point has to be taken into account in the operation of a power plant.

In our case, it requires a whole team of specialists per shut-down for more than 10’000 components revised.

A Mechanic adjusting belts of a Siemens blower

Tetrodes

Tube	Power [kW]	Units in operation	Pre-mounted spare	In box stored spare	Statistical lifetime [hours]	Remaining operation time [years]
YL 1440	1	8	2 = 25 %	36	16’500	5
YL 1520	10	4	2 = 50 %	34	11’000	6
YL 1530	35	72	8 = 12 %	135	31’200	10
RS 2004	135	20	2 = 10 %	36	21’300	**2**

The picture shows the tetrodes from left to right : YL 1440, YL 1520, YL 1530, RS 2004

The RS 2004 needs to be mounted with an additional cooling collector

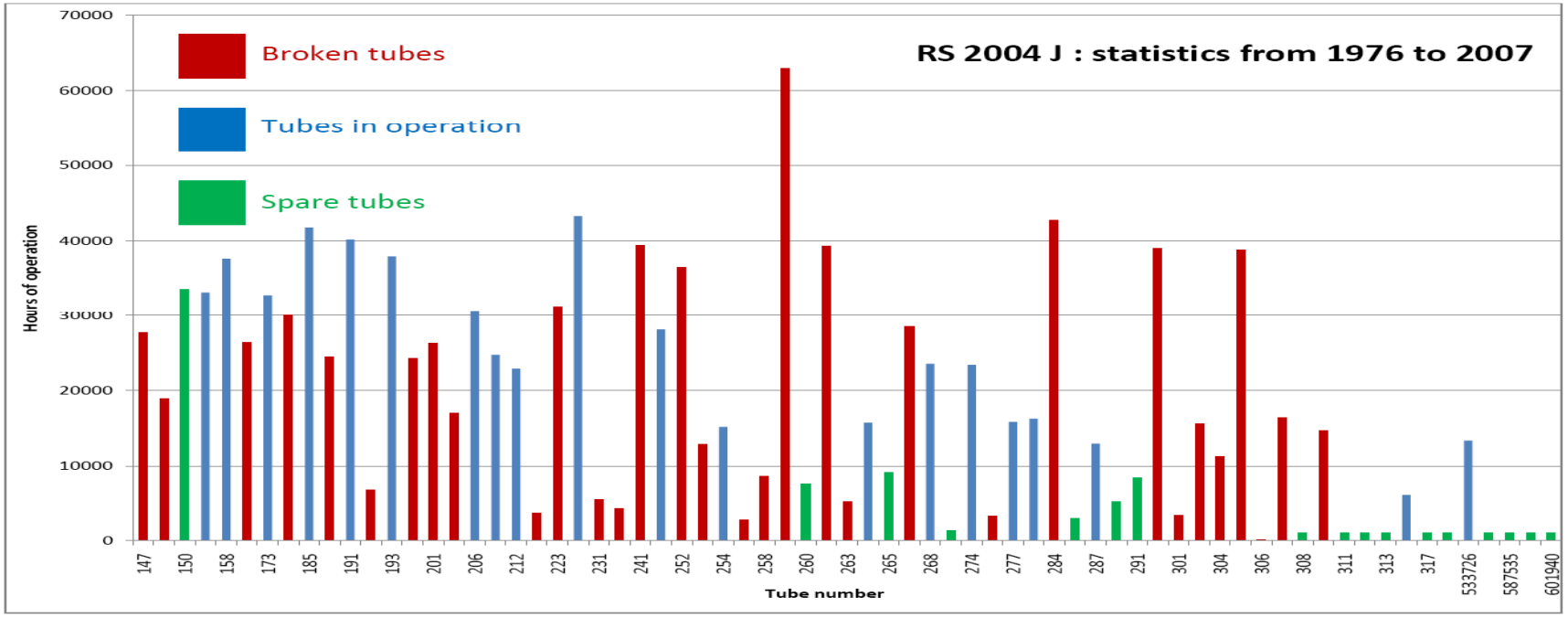
Tetrodes

First storage philosophy :

Run each tetrode to the warranty time, store it, run it again later.

It seems we have a lot of spare tubes, but are they still reliable ?

The first new Thales tetrode seems to be strong. We now have two years of operation (13'300 hours) with the first tetrode.



Tetrodes

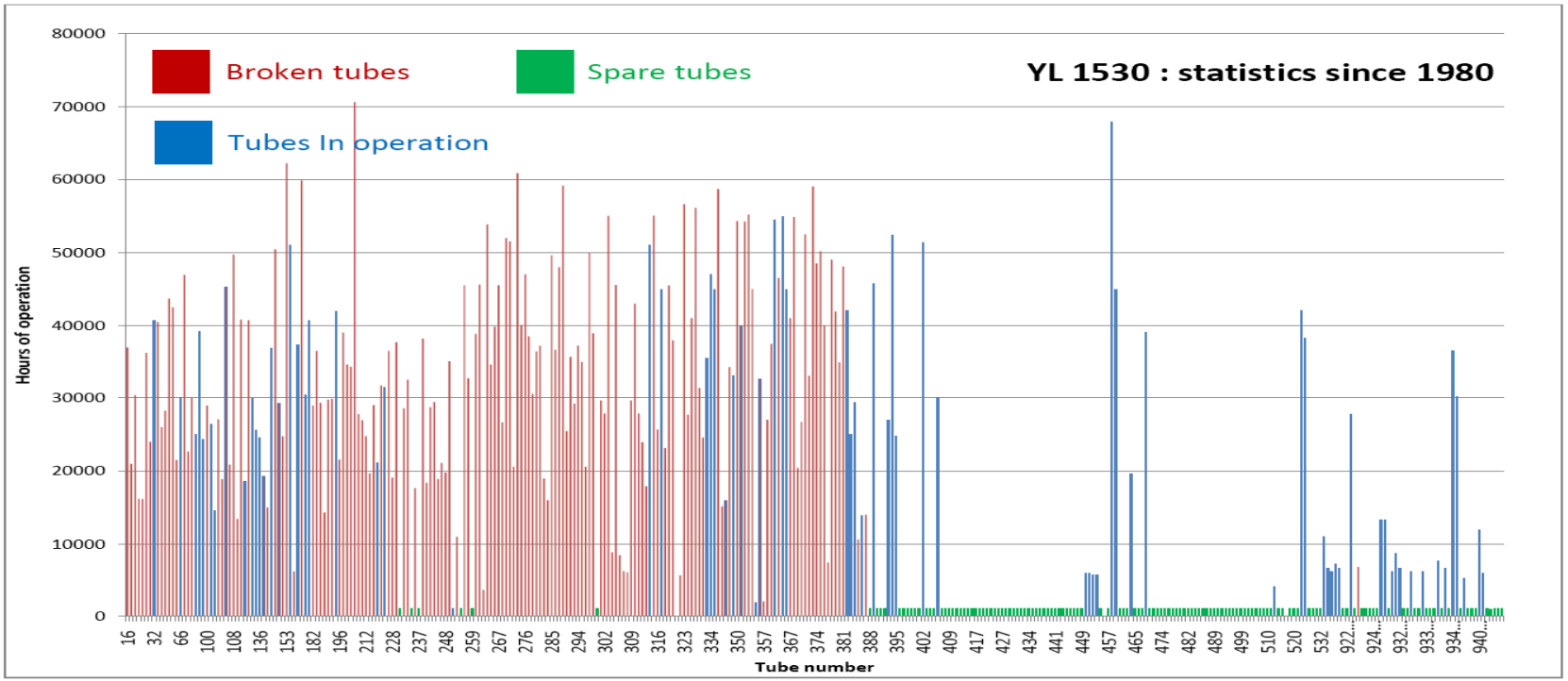
Second storage philosophy :

Run each tetrode to the end.

Lose warranty and are all the old stored tubes still operational ?

We started to check several batches with different delivery time.

The new tubes from Covimag also seem to be strong enough.



Tetrodes

Third solution chosen :

Run the old tetrodes to the end.

And run the very new tetrodes to have some statistics

Finally, we would like to :

- increase our RS 2004 stock.
- reduce our YL 1530 stock.

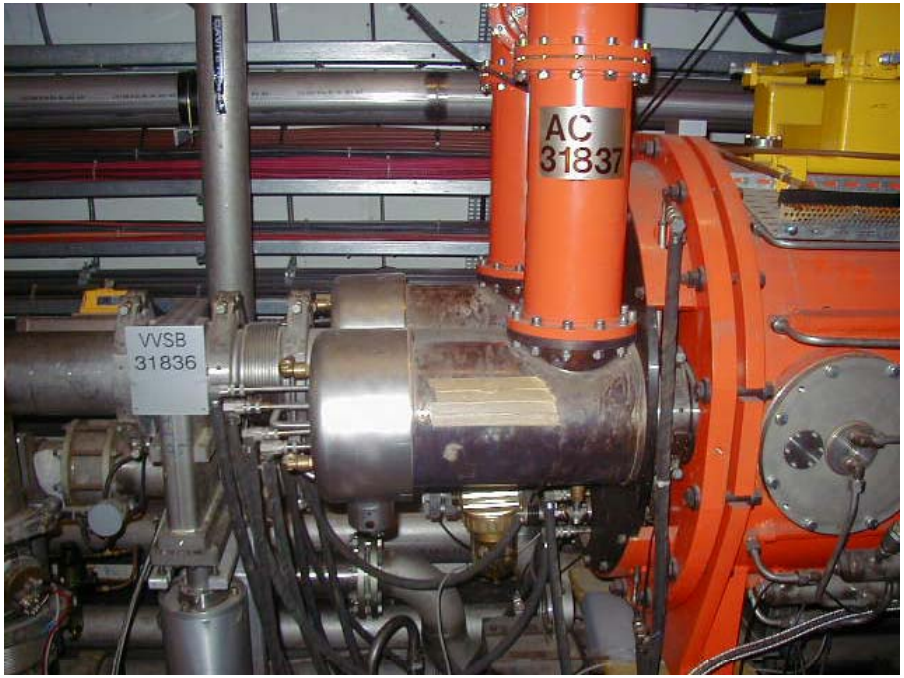
Nevertheless, we will still order some YL 1530 to keep the supplier's "know how" and the production alive.

The actual RS 2004 stored tetrodes : only 12 new tetrodes

The actual YL 1530 "old-new" stored tetrodes : 135 tetrodes

Power coupler

In the late 1990's, cracks appeared in the ceramic power windows.



The old cylindrical ceramic power coupler
375 kW cw

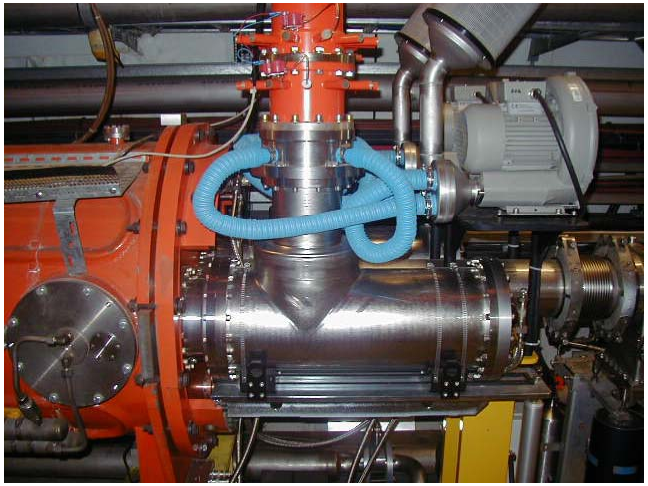
Broken cylindrical ceramic

Power coupler

We decided to design new higher power coupler, based on a commercial disk ceramic.

Finally a TH 20571 Thales modified klystron window has been selected.

The TH 20571 Thales disk ceramic



The new disk ceramic power coupler 500 kW cw

Power coupler

Two couplers are mounted face to face on the test cavity.

This assembly is connected with :

- One side to a 1 MW line
- The other side to a 550 kW load

We tested the new coupler up to:

- 550 kW cw (at the limit, overheated).
- 800 kw pulsed 10 µs / 23 µs.

The test cavity with two couplers face to face

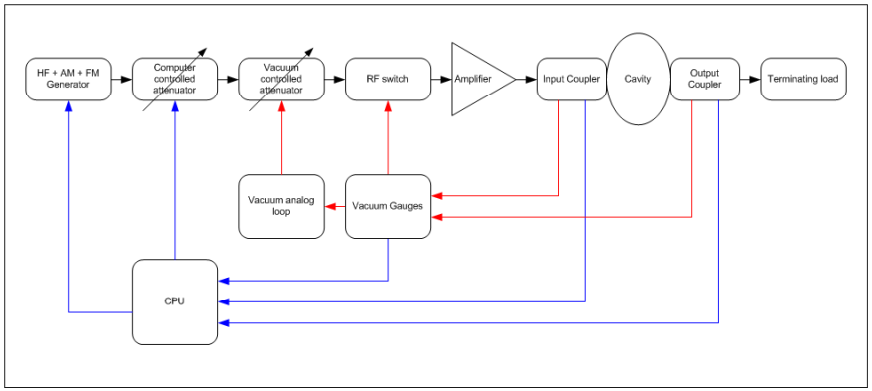
The test cavity and couplers connected to the power amplifier and load

Power coupler

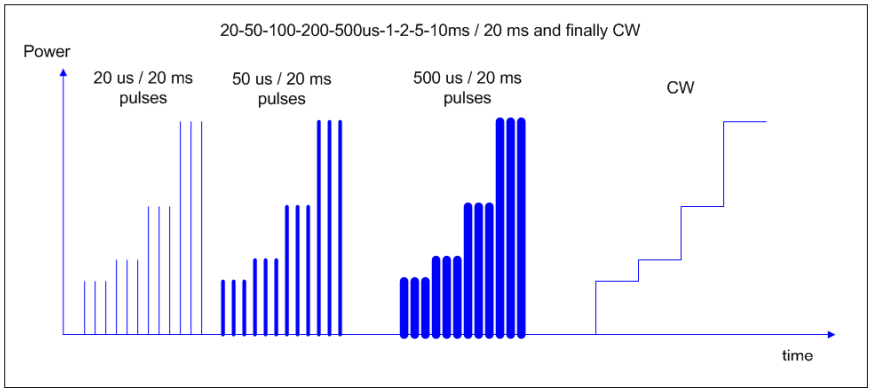
In 1999, to do the tests, we also implemented a new automated conditioning system :

- RF is never applied if pressure exceeds 2.5 x10-7 mbar.
- Process always starts, with very short pulses, 20 µs every 20 ms.
- Power level is increased with short pulses up to full power, passing slowly through all power levels.
- Finally, restart the same process from low power level with longer pulses.

This principle has been re-used for the LHC coupler conditioning.

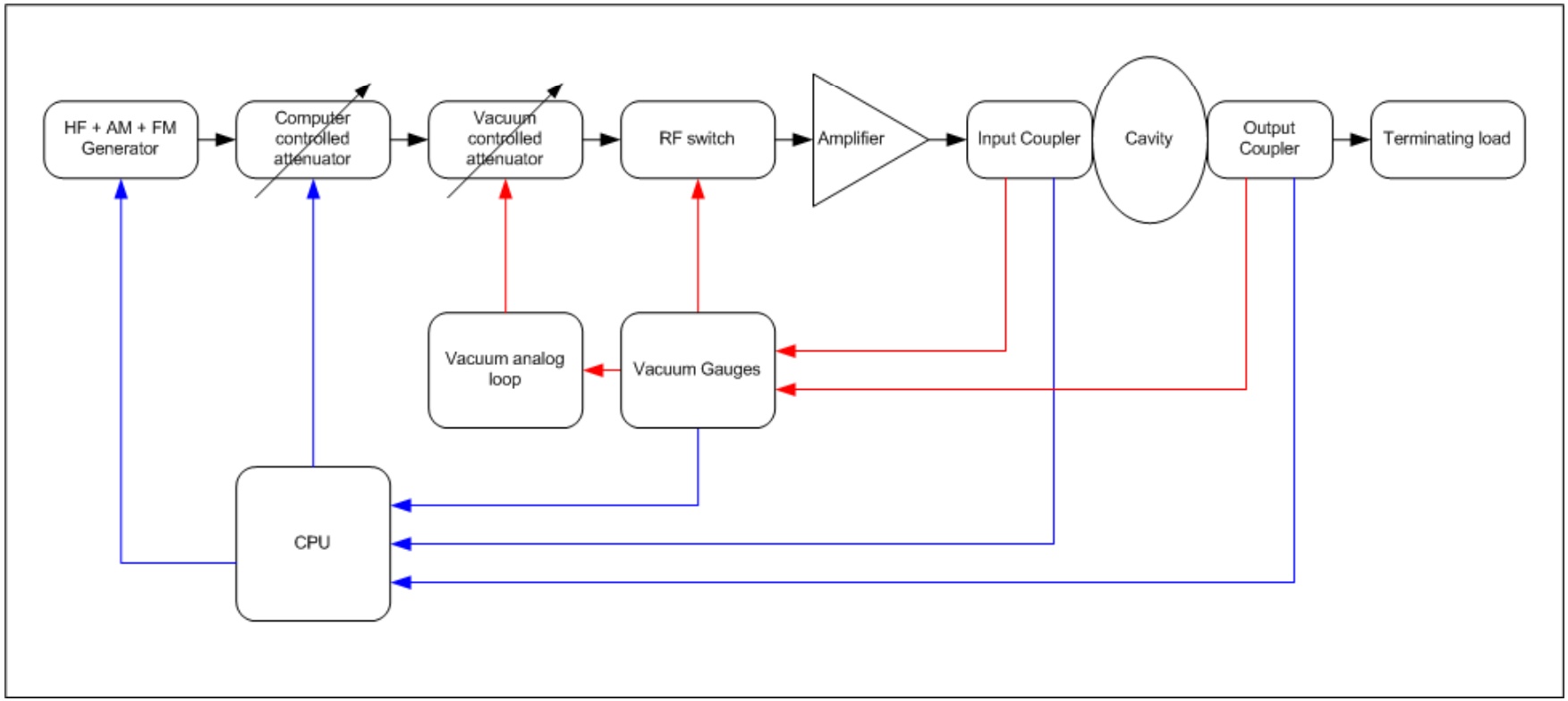


Principle of the conditioning system :
An analog loop always looks at the vacuum
A digital vacuum controlled loop increases the power



Always start with short pulses
Increase the power
Increase the length of the pulses

Power coupler



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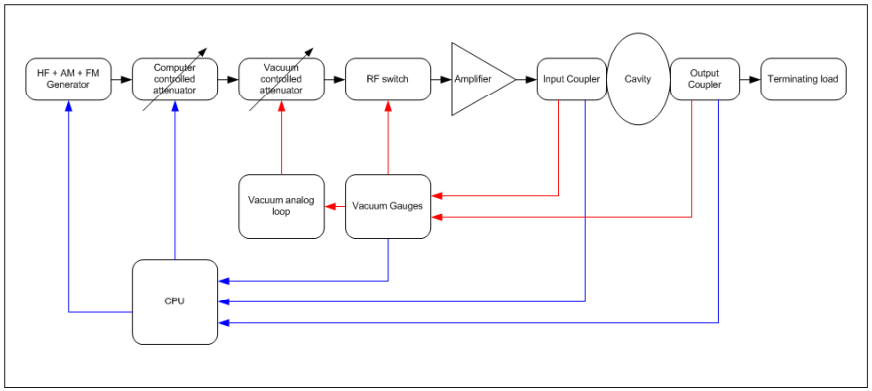

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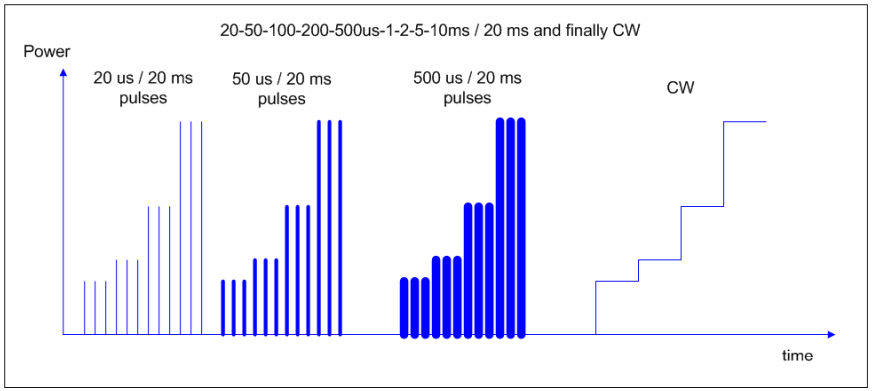


Always start with short pulses
Increase the power
Increase the length of the pulses

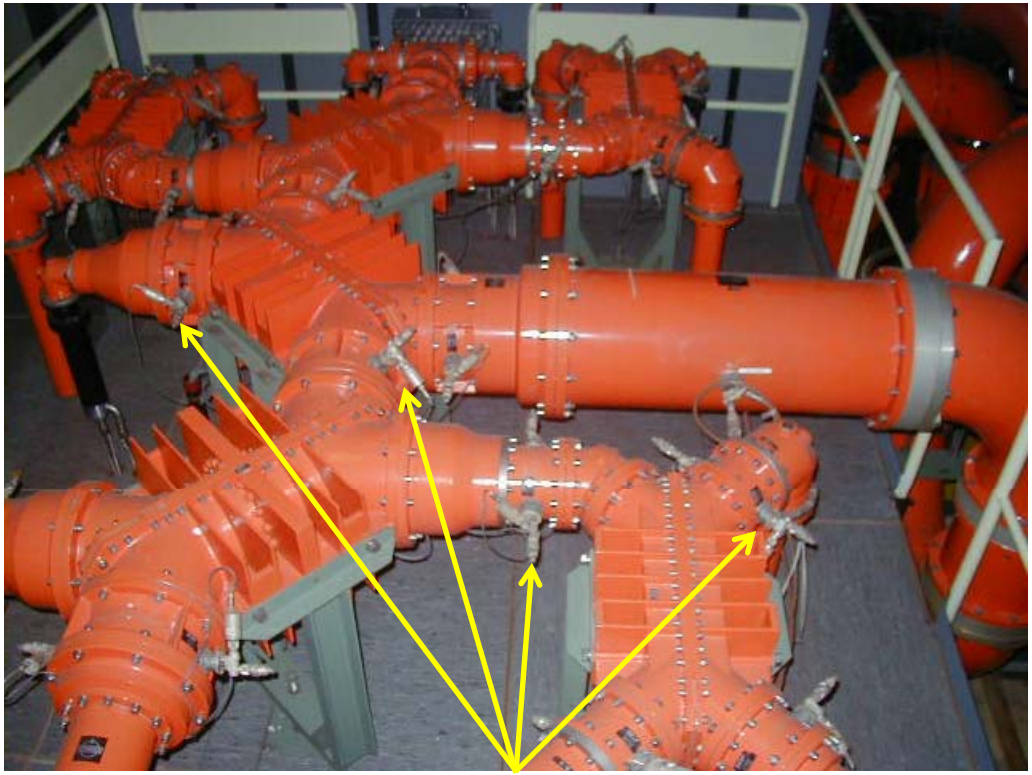
Combiners and lines

As built in 1980.

More than 116 splitters and combiners.

740 directional couplers with detectors.

Never had any major problem !



A Philips hybrids plant
with directional couplers and RF detectors

The Spinner coaxial 1 MW power combiner

Power loads

Over all the splitters and combiners, we also have more than 120 x 50 kW water cooled power loads.

With time the silver deposit on each side of the 50 Ω resistor is removed by water, then we lose the RF contact.

Every four years, we fully dismount the loads and re-do the silver deposit.

50 kW water power loads

A power load after a water cooling fault

Power loads

At the outputs of the main combiners and cavities, we have 16 x 550 kW water cooled power loads.

After 22 years of operation, we had our first problem with these loads.

It is due to corrosion from the stagnant water present during the 3 months per year shut-down.

Set of two 550 kW power loads

Last broken load with water over the air side

Corrosion effect due to stagnant water during the 3 months per year shut down

Power loads

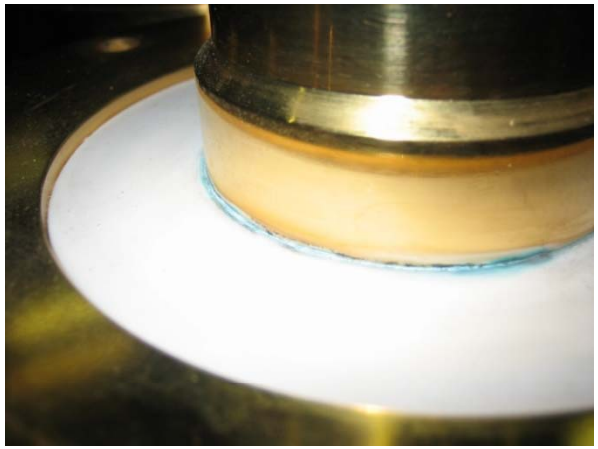
We re-designed a new ceramic window with a massive copper inner brazed directly onto it.

We tested with success the new design up to 580 kW cw and 800 kW pulsed 10 µs / 23 µs.

We also tested with success two new pre-series loads for two years in operation.

Last week we finished the exchange of all the loads and we found that 12/14 loads were about to break.

The new power loads on cavity #1



The old windows removed just on time

Power converters

All the anode power converters are conventional 3-phase full wave rectifier :

- 4 x 150 kVA Siemens driver :
  - 400V AC -> 7 kV DC / 21 A
- 4 x 1.0 MVA Siemens final :
  - 18 kV AC -> 8.5 kV DC / 120 A
- 4 x 1.2 MVA driver and final Philips :
  - 18 kV AC -> 10 kV DC / 120 A

We have already seen the effects of reduced preventive maintenance.

The “Siemens” driver HV power converters 4 x 150 kVA

The “Siemens” final HV power converters 4 x 1.0 MVA

The “Philips” common driver and final HV power converters 4 x 1.2 MVA

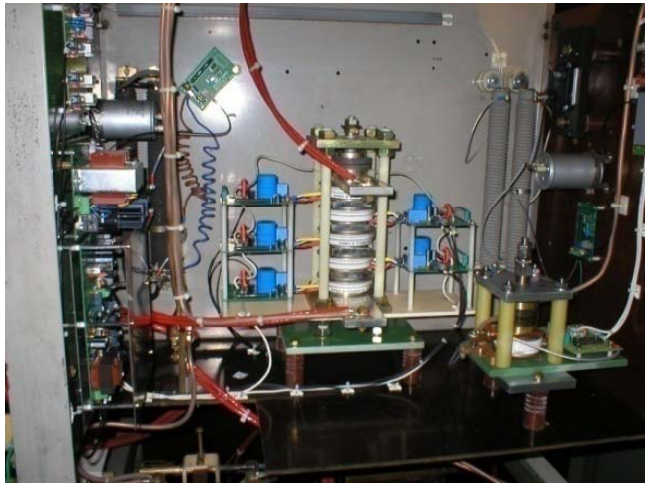
Power converters

All these anode power converters were equipped with a mercury ignitron crowbar to divert the energy in the event of a tube arc.

In 1997, a capacitor explosion vaporized the mercury of one of these ignitrons over all the BA3 building. The SPS was stopped 2 months, and all the equipment had to be cleaned due to the corrosive smoke of the fire.

We exchanged all the mercury ignitron with fast GTO stacks and installed fire detection inside all the power supplies.

The old mercury ignitrons



The new GTO crowbar stack

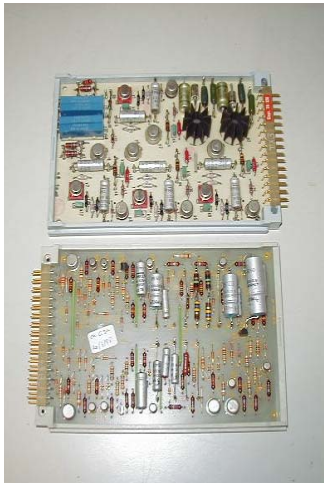
Interlock and Control

All our 500 kW amplifiers are equipped with a hardwire interlock system to protect the equipment in case of failure in :

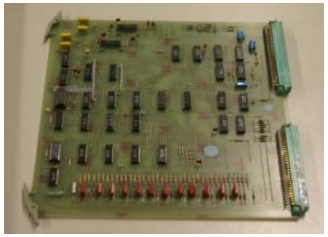
- Cooling system
- Power converters
- Amplifiers
- …

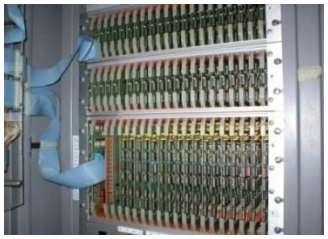
The Siemens amplifier employs discrete transistor industrial logic.

The Philips plant uses CMOS logic cards with wire wrap connection



The Siemens transistor based control logic and interlock





The Philips CMOS wire wrapped control logic and interlock

Interlock and Control

Local control racks are provided for :

- switching
- Monitoring
- interlock indication.

These interlock and control system did not generate any machine downtime since 1980 !

Be careful with the new PLC based system to keep all these functionalities.

The “Siemens” switching, monitoring and interlock indication panel

The “Philips” switching, monitoring and interlock indication panel

Infrastructure

The cavities are in the SPS, 60 meters under ground level.

We had a vault problem with water infiltration.

We tried to protect the cavities, but the ceiling on top of cavity #2 was too damaged.

We had to repair it, but as the work is quite long, 2 months, we had to wait until the 2005 off year to repair the vault.


The BA3 vault in 2005

Removal of the transmission lines

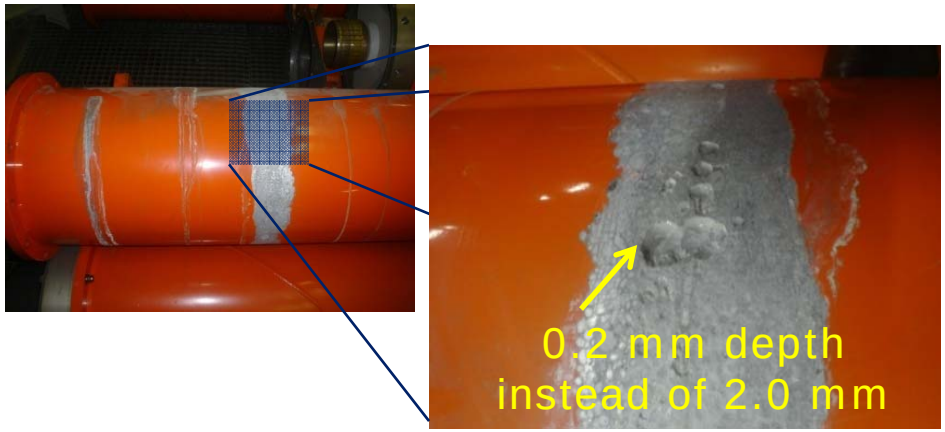

The new vault in BA3 in 2006

Infrastructure

When we removed the coaxial line, we discovered that the water mixed with some saltpetre, has a destructive effect on the aluminium outer conductor.

In addition, the infiltration water has also a destructive effect on the vacuum seals of the cavity.

We had to change all the drift tube and antenna vacuum seals on two sections of cavity #2, more than 70 vacuum seals. Very delicate work, because the drift tubes must be precisely aligned.



Effect of the water + saltpetre corrosion

What next

As we are the last RS 2004 user, and as the YL 1530 has no long term guarantee of availability,

We would like to test the new diacrode TH 628, given for 1 MW cw @ 200MHz, as a replacement tube.

We could then replace 88 final tetrode power amplifiers with only 8 diacrode power amplifiers.

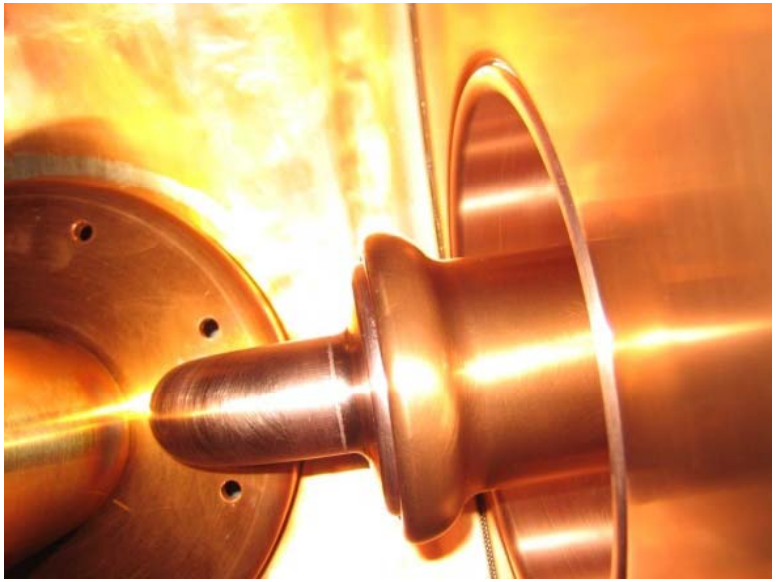
We already have the tube, we will start studies as soon as possible.

Our first Thales TH 628 Diacrode already delivered at CERN

What next

If we want to improve the power levels, we also have to improve the connection of the coupler to the first drift tube.

We then have to install a cooling for the power coaxial transmission line.



The picture shows the actual weak point : the connection of the coupler to the first drift-tube

Additional cooling for the air side of the power load

Conclusion

RF power components are not indestructible :

- Main power couplers
- Power loads
- Tetrodes

Never neglect preventive maintenance, it is the key for :

- Reliable operation.
- Safe operation.

Project	Design and first prototype	Tests of pre-series	Series
Power coupler	1	1	3
550 kW Power loads	1	2	2
Crowbar	1	1	2

Time in years for the design, tests of pre-series, construction and installation of series

Conclusion

I hope to see you tomorrow for the visit of these power plants.

Thank you very much for your attention.