Status and Operation of the ELETTRA RF System

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**FERMI, **Machine operation*

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ELETTRA Storage Ring:

- **Operations** — **2.0 / 2.4 GeV** — **320 / 130 mA**
- **4 x 500 MHz RF plants** — **- 3 x 60 kW klystron based transmitters**
  - 1 x (2 x 80 kW) I.O.T. tube transmitters
  - 4 single cell normal conducting cavities

ELETTRA Injector:

- **100 MeV Linac & full energy Booster**
- **1 x 500 MHz RF plant** — **- 1 x 60 kW klystron based transmitter**
  - 1 x 5 cells Petra type cavity
- **User operation from 4 March 2008**
- **Storage Ring re-fill is working fine**
- **Top-up operations foreseen within the end of 2009**

Klystron based Transmitters faults in one year

✓**Aging breakdowns**

✓ **User operation with 3 RF plants during repair , max 250 mA @ 2.0GeV**

January –High Voltage cable discharge in RF transmitter # 2:

- **Dielectric insulation of 25 kV cable lost. The discharge has damaged several electronic components, not the klystron!**
- **down-time 8 hours; total replacement time: 3 days**
- **Replacement of the same cables in all the transmitters**

July - 188 kVA Power Supply transformers replacement in RF transmitter #3:

- **failure of one low voltage winding (10590 V @ 94 kVA).**
- **down-time 6 hours; total replacement time: 1 day**
- **From the beginning of ELETTRA commissioning in 1994 : 3 PS replacement (last in 1999).**

One Klystron's replacement

- April - Klystron replacement in RF transmitter # 3:

-after ELETTRA injection, the maximum output power was only 40 kW
-raised the collector current set but the gain was not restored
-fast drop of the collector current - from 5.2 to 4.6 A in half hour
-switched OFF the transmitter: down-time 2 hours, only 3 RF plants ON
-next day the klystron's replacement started: it lasted 4 days , including transportation, dummy load test etc.

The Klystron was Marconi k3672 BCD s/n 0994-0121 , lifetime 32557 hours, installed last September 2003

Lifetime of the installed klystrons updated to 21-Sep-2009

RF plant	klystron	model	serial	hours	installation date
#2	EEV	k3672 BCD	867-9904	64247	April-99
#3	E2V	k3672 BCD	1105-0428	3067	April-09
#8	E2V	k3672 BCD	1038-0212	29060	October-04
booster	E2V	k3672 BCD	1083-0351	6735	August-07

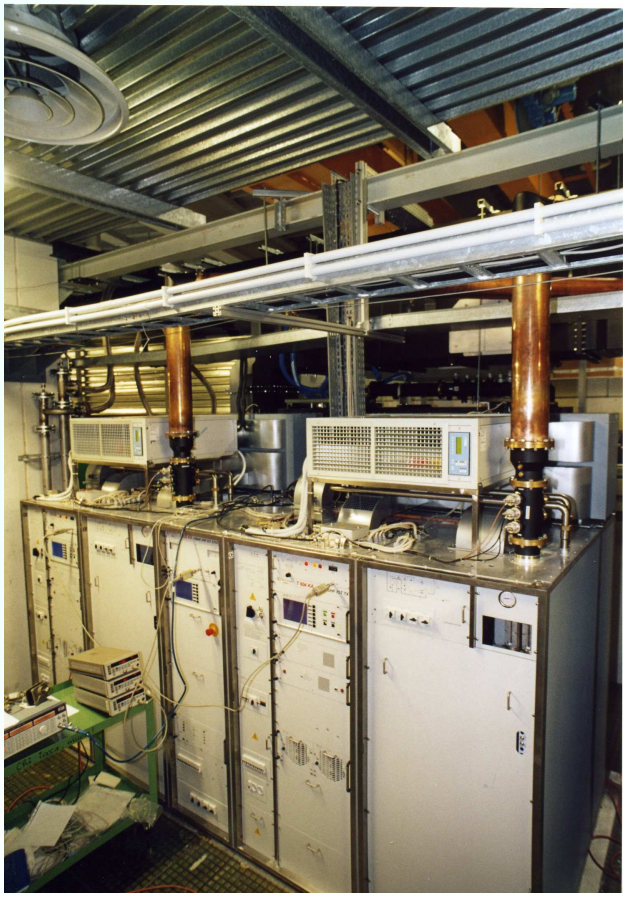
A new klystron was installed in the booster's amplifier at the beginning of the booster RF plant installation. It works in cycling mode at 2.2 Hz, ramping from 0.5 kW to 35 kW.

Storage ring's klystrons #2, #3 and # 8 operate in C.W. from 30 kW to 55 kW following the accumulated electron current power demand.

IOT based transmitter in section #9

Two 80 kW transmitters, Tx-A and Tx-B, are combined together by means of a waveguide switchless combiner.

High flexibility: both transmitters can output power on the cavity OR one on the unbalanced load and the other on the cavity at the same time, by adjusting the phase of the combiner .



October 2008 I.O.T. TH 793-1 installation on Tx-A

- ✓The TH 793-1 was shipped already installed in its trolley. Same input circuit of the TH 793 and new output cavities.
- ✓Sincrotrone Trieste provided for:
- •additional cooling system for the output cavities
- •6 1/8" output coaxial line
- •attenuated RF drive to limit the output power to 65 kW, during the ELETTRA run
- ✓the tube installation and set up was done by Thales personnel
- ✓140 kW were certified on dummy load running the TH 793-1 s/n 617303 (Tx-A) and the TH 793 s/n 557132 (Tx-B) together
- ✓no faults occurred during installation/check time

TH 793-1 and TH 793 main parameters Oct-2008

TUBE	Grid (V)	Grid (mA)	HV (kV)	Ibeam (A)	Driver (W)	Driver rff(W)	Body cur. (mA)	FWR Power (kW)	RFL Power (kW)	Efficiency (%)	Gain (dB)
TH 793-1	-101	0.0	35.1	1.60	94	1.0	16	**19.9**	0	35.43	**23.26**
TH 793	-113	13.7	35.1	1.55	91	1.0	16	**19.3**	0	35.47	**23.26**
TH 793-1	-101	0.0	35.1	2.28	167	0.0	17	**41.7**	0	52.04	**23.97**
TH 793	-113	16.0	35.1	2.22	163	1.0	17	**40.0**	0	51.29	**23.90**
TH 793-1	-102	0.0	35.1	2.75	231	1.0	20	**58.9**	0	61.00	**24.07**
TH 793	-113	19.0	35.1	2.72	229	2.0	24	**59.6**	0	62.50	**24.15**
TH 793-1	-102	-26.0	35.1	3.29	312	4.0	28	**79.8**	0	69.16	**24.08**
TH 793	-113	19.5	35.1	3.26	308	4.0	44	**79.1**	0	69.20	**24.10**

From October, 20 both transmitters were working:

- Tx-A TH 793-1 new tube on WG combiner unbalanced load
- Tx-B TH 793 (6000 hrs) on the ELETTRA cavity (max power 61 kW)

Both were driven by the same RF signal: its level is set by the cavity's amplitude loop control.

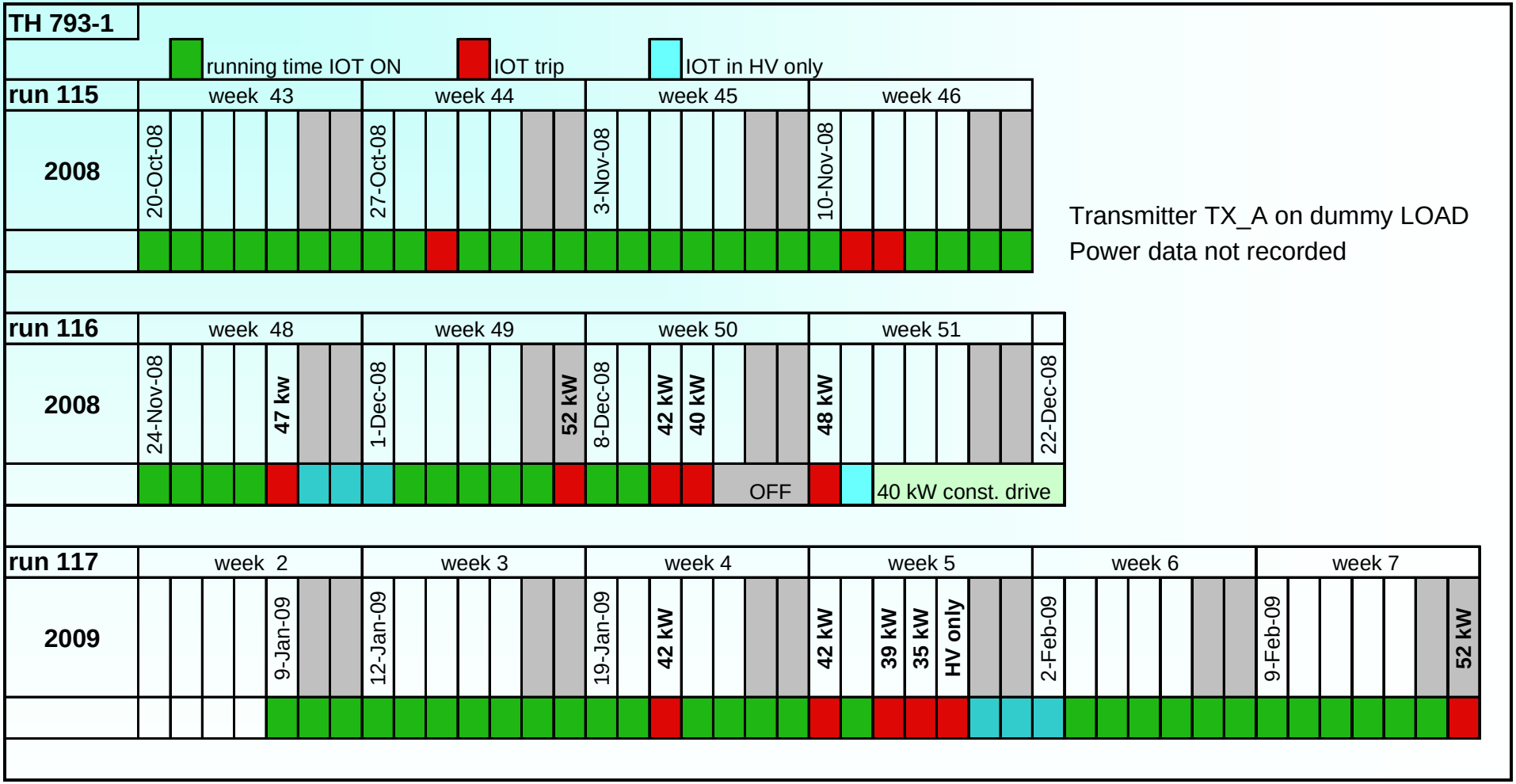
Due to the large numbers of TH 793 trips, "HV Inhibit" (one each 2/3 days), from November Tx-A was feeding the ELETTRA cavity (max power 65 kW).

The so-called "HV Inhibit" tube fault is issued when

- BEAM OVERCURRENT $I_{beam} > 4$ A
- BEAM CURRENT SPIKE slope> 35A/μsec

From October all the trips were monitored and recorded with a dedicated scopes

TH 793-1 behaviour



TH 793-1 "HV Inhibit" on the scope

Reflected power from input circuit

Beam current

DC signal ~HV voltage (1:5000)

Logical signal of the fault

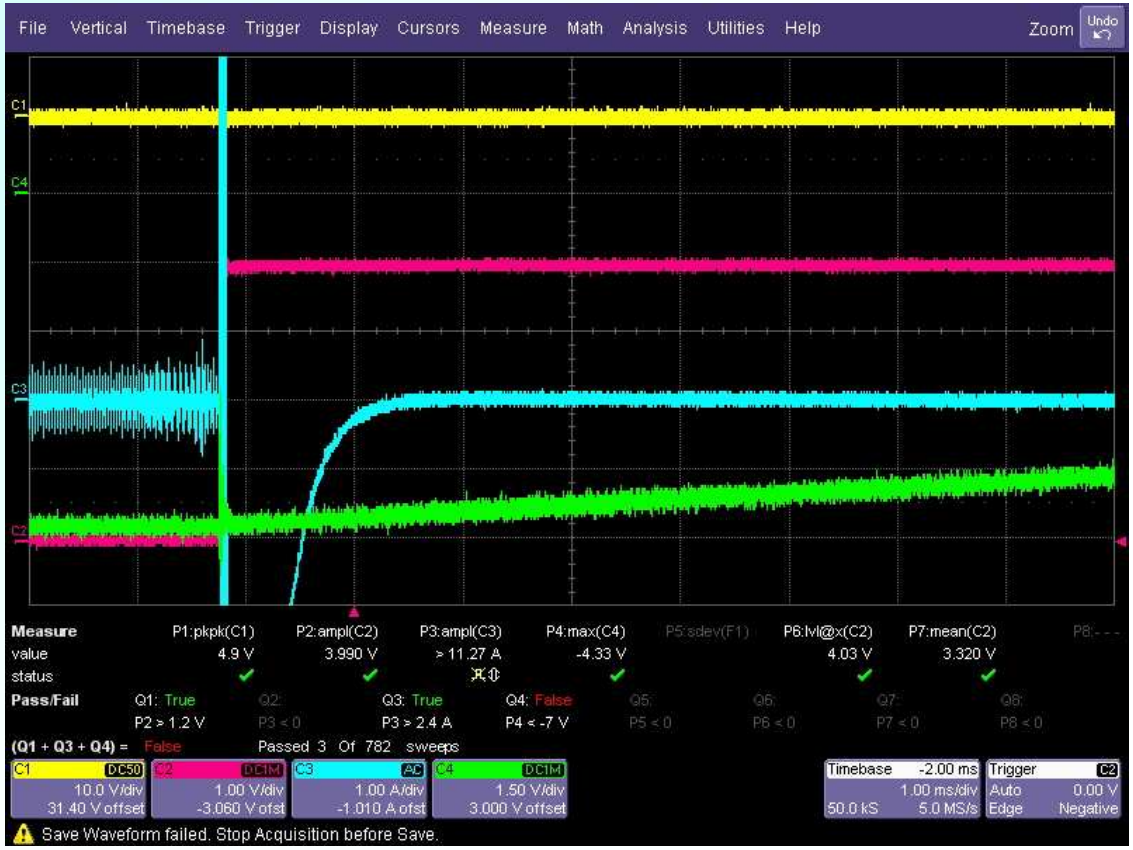
TH 793-1 "HV Inhibit" on the scope –no RF applied

RF Drive

Beam current

DC signal ~HV voltage (1:5000)

Logical signal of the fault

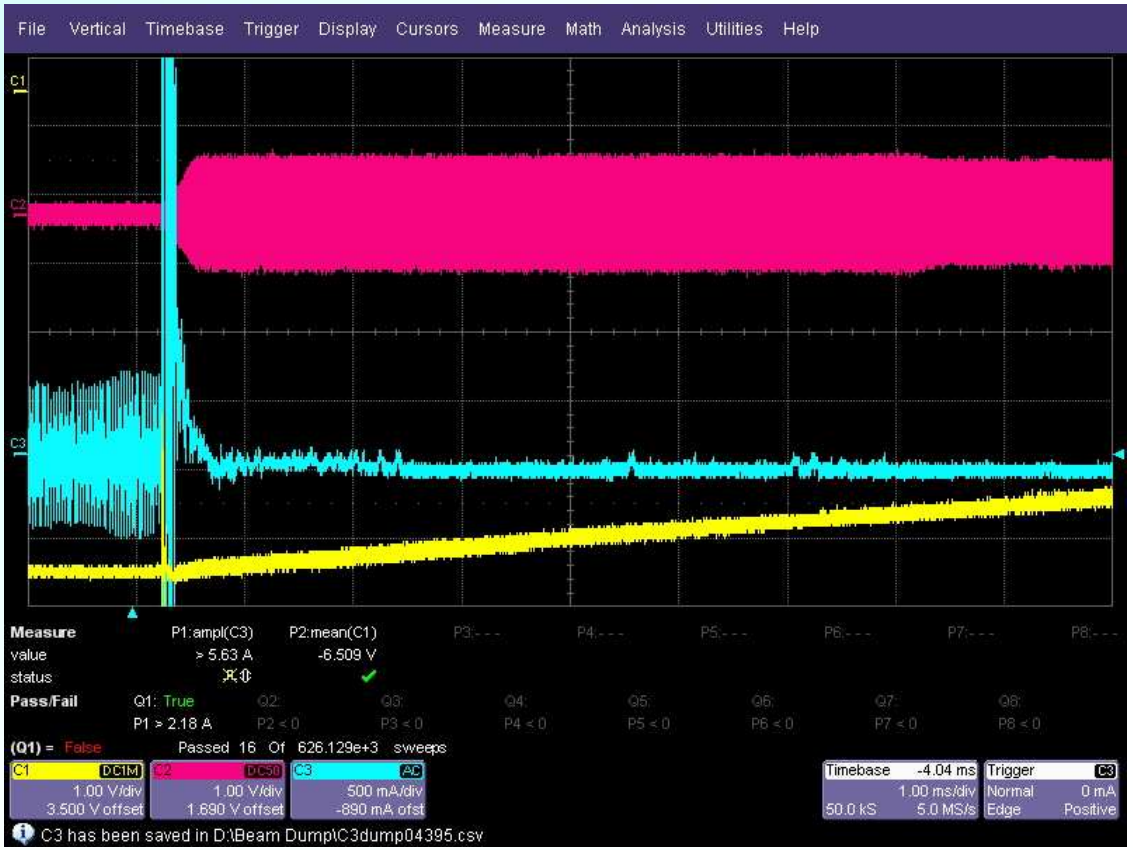


TH 793 "HV Inhibit" on the scope

RF Drive

Beam current

DC signal ~HV voltage (1:5000)



TH 793-1 and TH 793 troubleshoot

During the February shut down time both tubes were de-installed at the presence of Thales personnel.

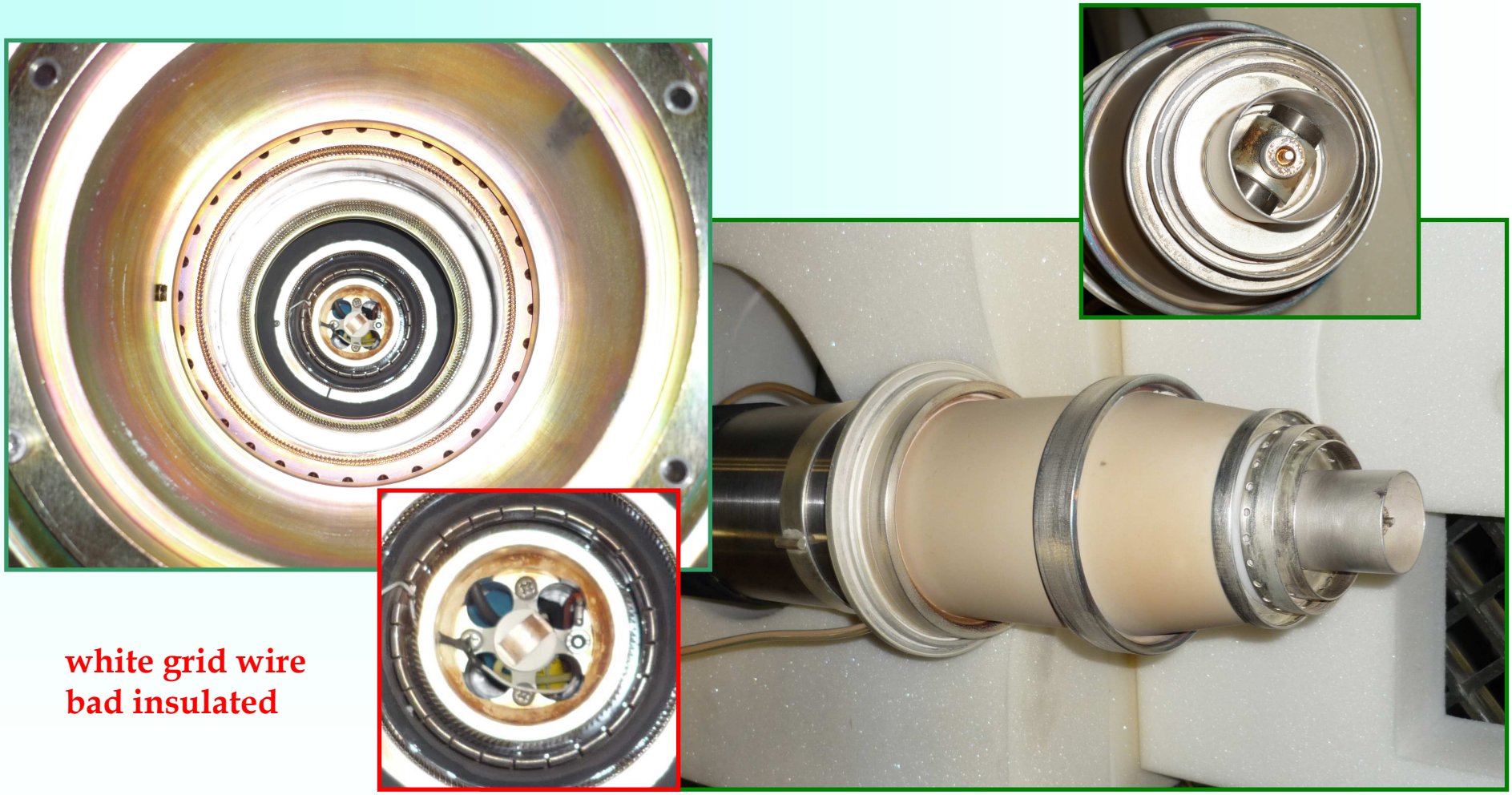
It was already decided to replace the TH 793-1's input circuit with the TH 18793 LS s/n 47 (loan from Thales).

Problems:

-TH 793-1 False contact between the grid wire and ground pole of ion pump in the input circuit. Breakdown not connected to the tube itself. Tube extensively checked.

-TH 793 Dark spot on the tube's ceramic and discharge imprint in the input circuit's insulator. It should be cleaned and re-conditioned : tube shipped back to Thales factory.

TH 793-1 and its input circuit

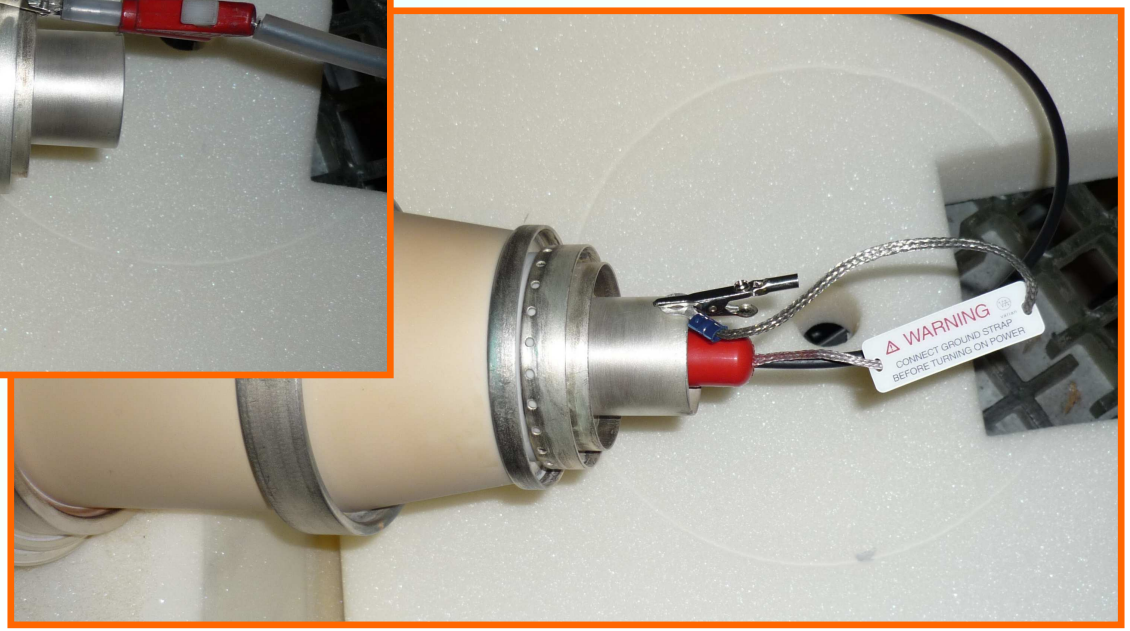


white grid wire
bad insulated

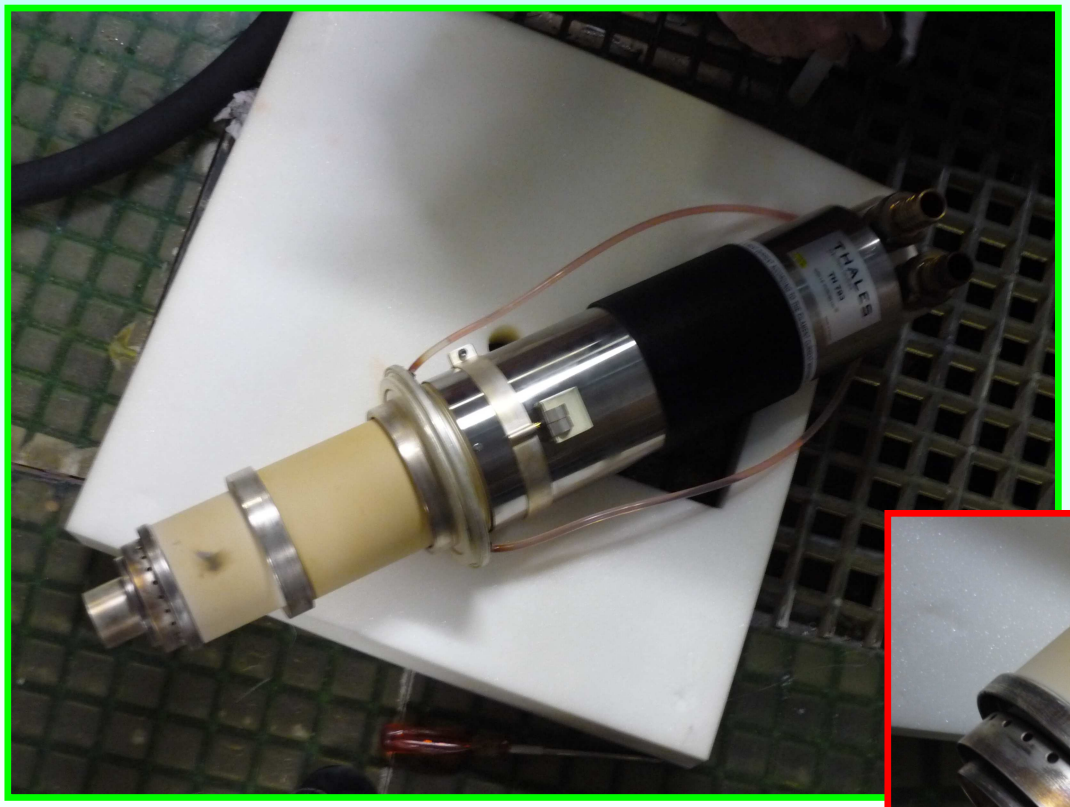
TH 793-1 check up

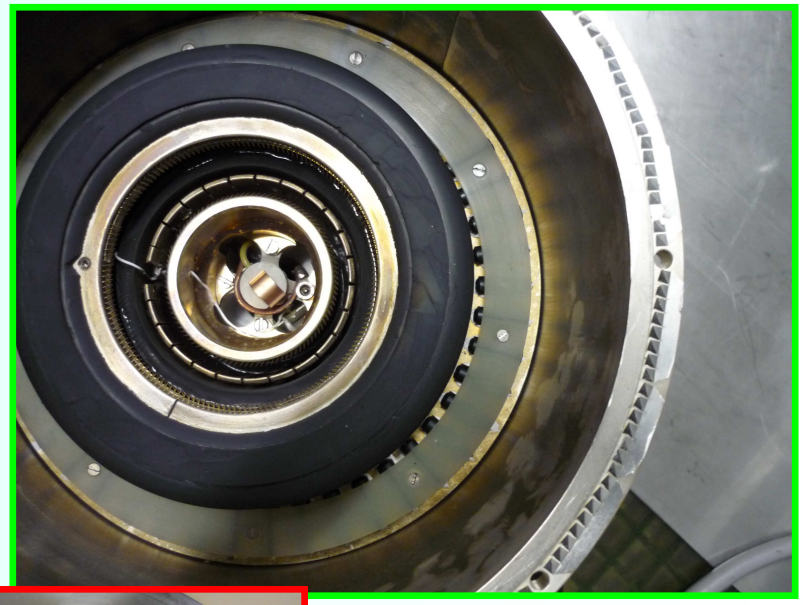
HV test

Vacuum test

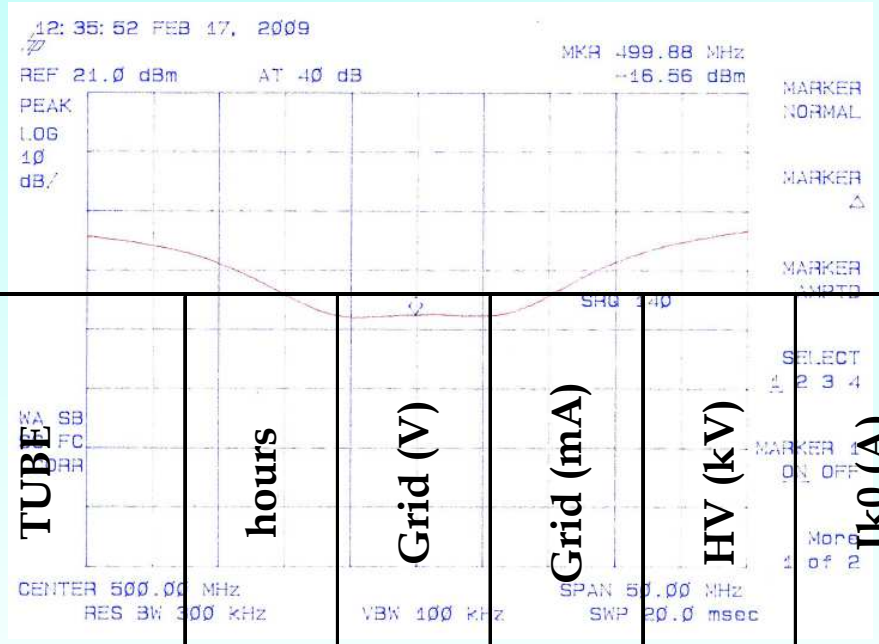


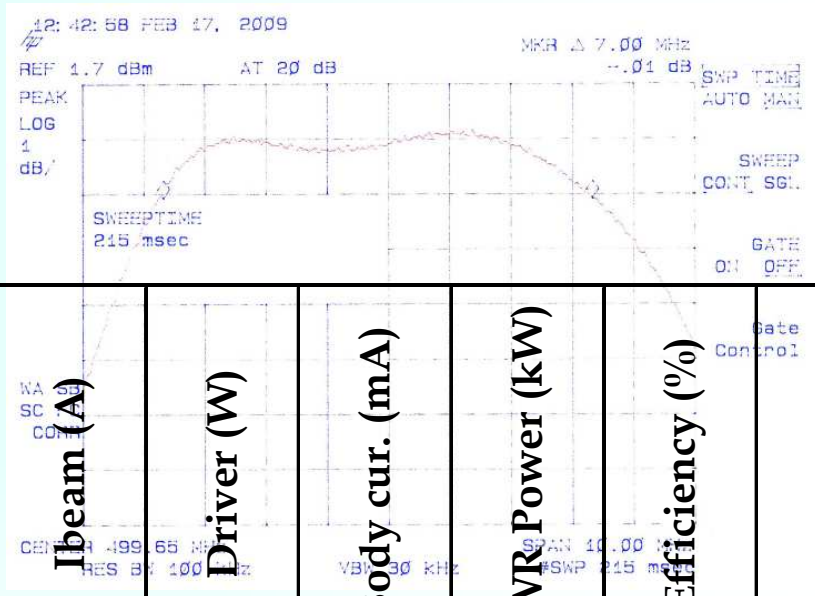
TH 793 and the input circuit





TH 793-1 and TH 792 CD parameters





TUBE	hours	Grid (V)	Grid (mA)	HV (kV)	Ik0 (A)	Ibeam (A)	Driver (W)	Body cur. (mA)	FWR Power (kW)	Efficiency (%)	Gain (dB)
TH 793-1 s/n 616303	2287	-99	26.8	34.3	0.16	2.35	197	16	**40.6**	50.37	**23.14**
TH 792CD s/n 005	1042	-105	5.1	34.5	0.16	2.28	176	4	**42.8**	54.41	**23.86**

TH 793-1 and TH 792 CD

IOT transmitter at end of February:

Tx-B: **TH 792 CD loan from Thales**

Tx-A: **TH-793-1 & input circuit 18793 LS s/n 47.**

After only 93 hours the final "HV Inhibit" (28/02/2009)

RF output power before the trip ~ 18 kW

tube vacuum O.K.

input circuit O.K.

the tube itself could not withstand more than 13 kV.

total filament hours 2378

TH 793-1 final "HV Inhibit

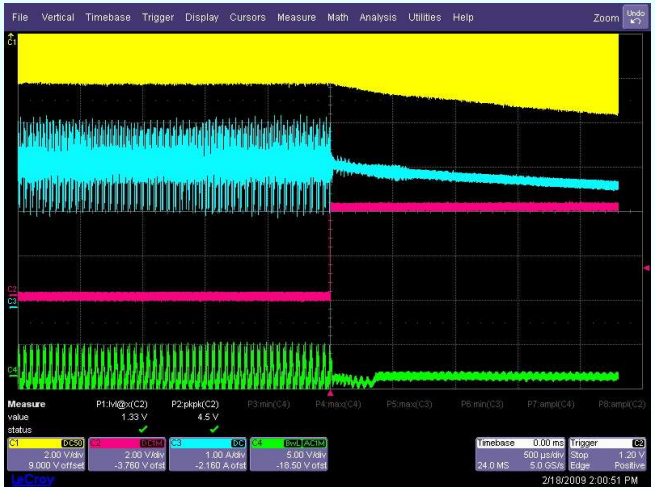
C1: Reflected Power

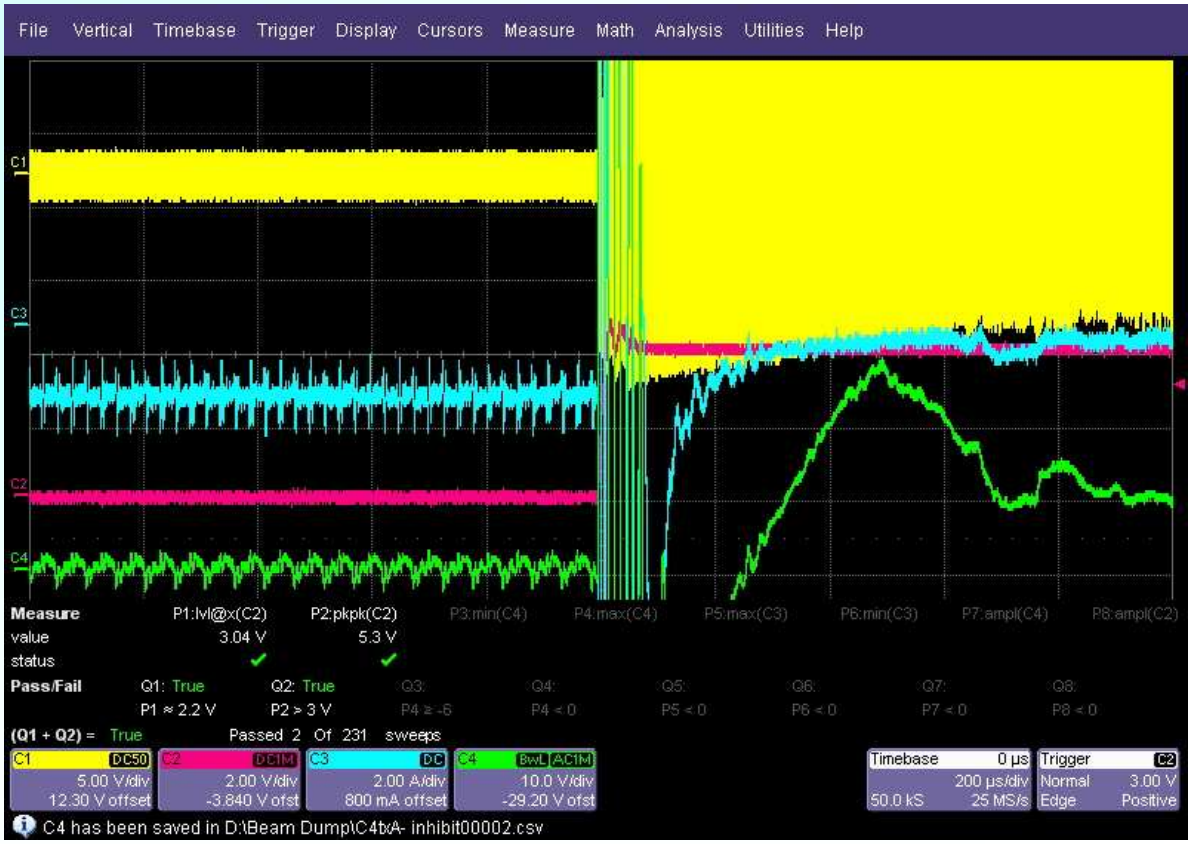
C3: BeamCurrent

C2: Inhibit logical signal

C4: Body Current

HV Inhibit test



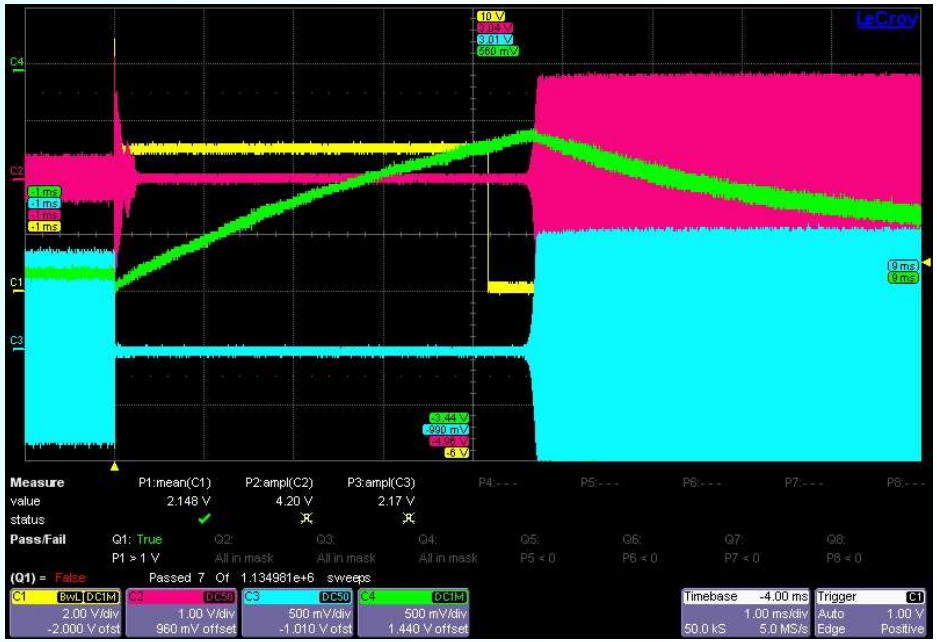


Cavity Amplitude Loop Modification for IOT Transmitter

The Elettra Beam Dump procedure is the interlock procedure to "kill" the accumulated electron current. It is done by switching OFF the RF for 4 msec.

The 500 MHz main RF generator STOPS for ~ 4 ms. NO driving signal for amplifier and no RF power in the cavities during this time interval.

At the beam dump, the amplitude control loop opens its control at the maximum output power the RF amplifier in accordance to the cavity voltage set by control -always 600 kV. When RF power back, the frequency loop starts to tune the cavity and the original power level is restored (~60 sec).



Reflected power Forward power

Beam Dump Signal Amplitude loop control

Cavity Amplitude Loop Modification for IOT Transmitter

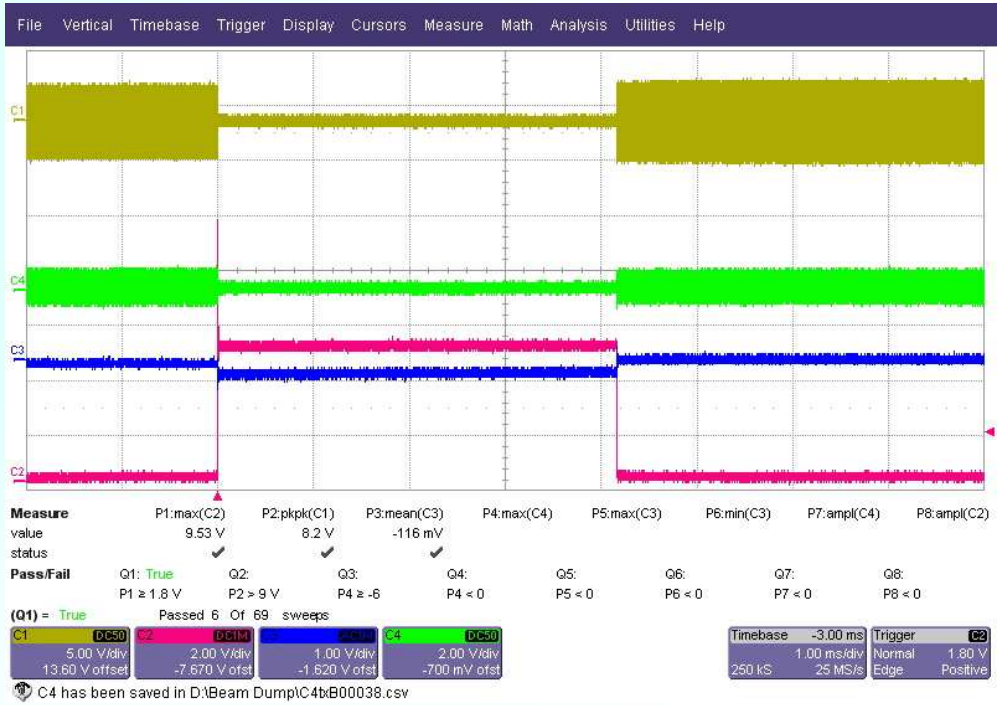
The beam dump procedure implies a sudden ramp to full RF power (raise time ≈300 μsec).

Is this sudden demand of full power somehow responsible for the wear and bad reliability of tubes? Does it stress the tube – cathode and grid?

-From October '08 the maximum RF power has been limited to 65 kW

-From February '09 the amplitude loop is "frozen" in case of the beam dump.

The IOT transmitter is driven back at 30 kW (ramp to 30 kW in 300 μsec , but it should be reminded that the transmitter is "hot").



Forward power IOT Beam current

Beam Dump Signal Reflected power

Status of IOT transmitter

Tx-A:

No tube since end of February '09

Waiting for a new TH 793-1 tube installation from August.

Tx-B:

From February '09

installed TH 792 CD s/n 5 (3 "HV inibit" trip and max HV =19 kV after 2406 hours).

Installed TH 792 CD s/n 3 (few "HV inibit" repeated even at low RF power).

Installed TH 793 s/n 557132, some "HV inhibit" trips, but it is still working!

TH 793 parameters

TH 793 s/n 557132 hours 8272	Grid (V)	Grid (mA)	HV (kV)	Ibeam (A)	Body cur. (mA)	Filament curr. (A)	Driver (W)	Driver rff(W)	FWR Power (kW)	RFL Power (kW)	Efficiency (%)	Gain (dB)
Tube parameters after Thales refurbishing	-114	**19.3**	34.5	2.05	15.6	22.6	167	0.1	**35.4**	0.01	**50.1**	**23.3**
5 weeks run time, 893 hours, 4 faults "HV Inhibit"												
Tube parameters after all these trips												
	-114	**29.8**	34.5	2.06	15.8	23.1	164	0.1	**35.4**	0.01	**49.8**	**23.3**
	-115	31.0	34.5	2.27	20.4	23.2	196	0.3	42.2	0.01	53.9	23.3
	-114	33.9	34.5	2.47	23.1	23.2	227	0.8	48.9	0.02	57.4	23.3

Tx-A	**15064**	**hours**			
Type	**s/n**	**Start**	**Stop**	**hours**	**Notes**
TH793	559442	Jun-06	Jul-08	11364	max HV= 4.3 kV & low fil current. New reconditioning in Nov. 07 no success
TH792 CD	005	Aug-08	Oct-08	1036	**Thales loan**. Good behaviour
TH 793-1	617303	Oct-08	Feb-09	2283	Found damaged grid wire. Installed INPUT CIRCUIT TH 18793 LS s/n 37. **Thales loan**
TH 793-1	617303	Feb-09	Feb-09	2378	Tube TRIP - max HV =13 kV

Tx-B	**17417**	**hours**			
Type	**s/n**	**Start**	**Stop**	**hours**	**Notes**
TH793	557132	Jun-06	Dec-06	2463	Repeated HV Inhibit above 25 kW
TH793	574752	Dec-06	Jan-07	417	output ceramics discharge
TH790		Jan-07	Jan-07	18	**Electrosys' loan**
TH793	572382	Jan-07	Dec-07	4748	tube broken
TH793	557132	Dec-07	Feb-09	5809	Many trips. Dark spot on ceramic
TH792 CD	005	Feb-09	Jul-09	2406	**Thales loan**.Tube trip - max HV=19 kV
TH792 CD	003	Jul-09	Aug-09	663	**Thales loan**. Repeated HV hinibit at 25 kW.Try the reconditioning,no success. HV O.K., but repeated trips at 2-3 kW
TH793	557132	Aug-09			Installed after Thales refurbishing

New cavity in sec. #8

Cavity sec. #8 was installed in 1993.

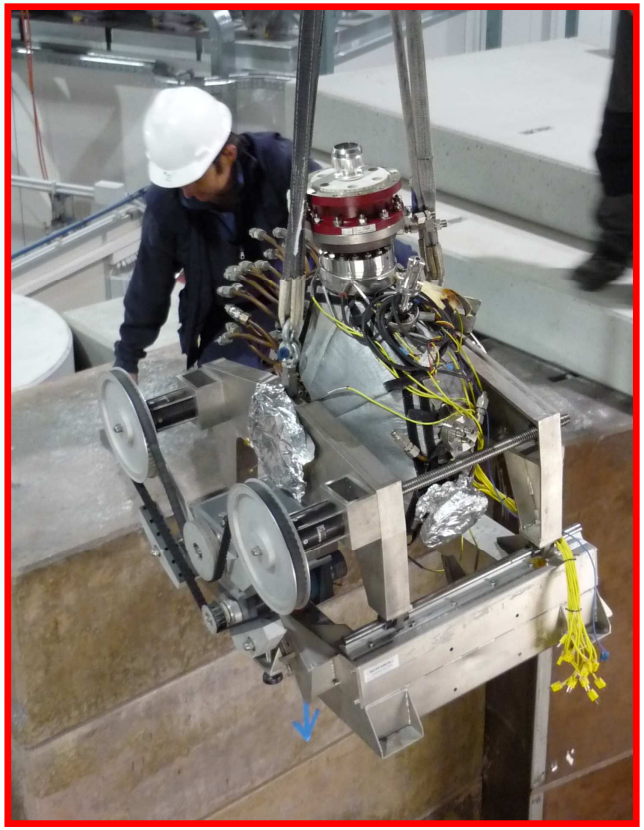
Old cavity's copper losses max 35 kW.

New cavity's copper losses max 62 kW.

De-installation of the old cavity : RF high and low power cables, controls etc, waters, vacuum.

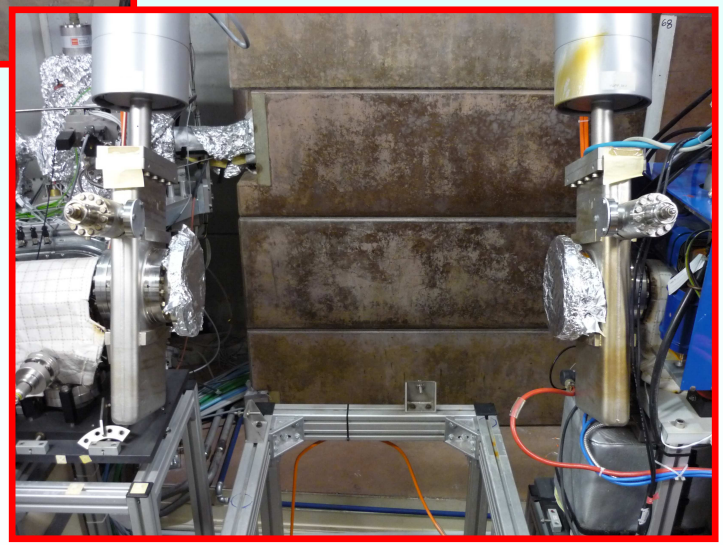
Arrangement of new cavity : alignment, mechanical and water connections, vacuum leak test, bake out, RF connections, RF power conditioning (1 day- cavity already conditioned in lab), controls, calibration.

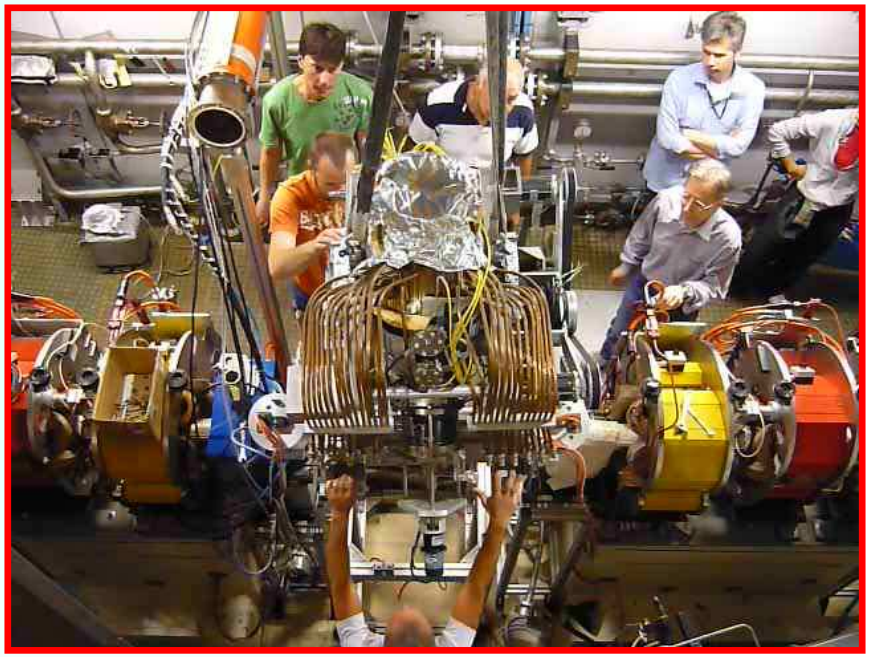
June shut down : total of 13 working days



Old cavity removal

Installation of the cavity



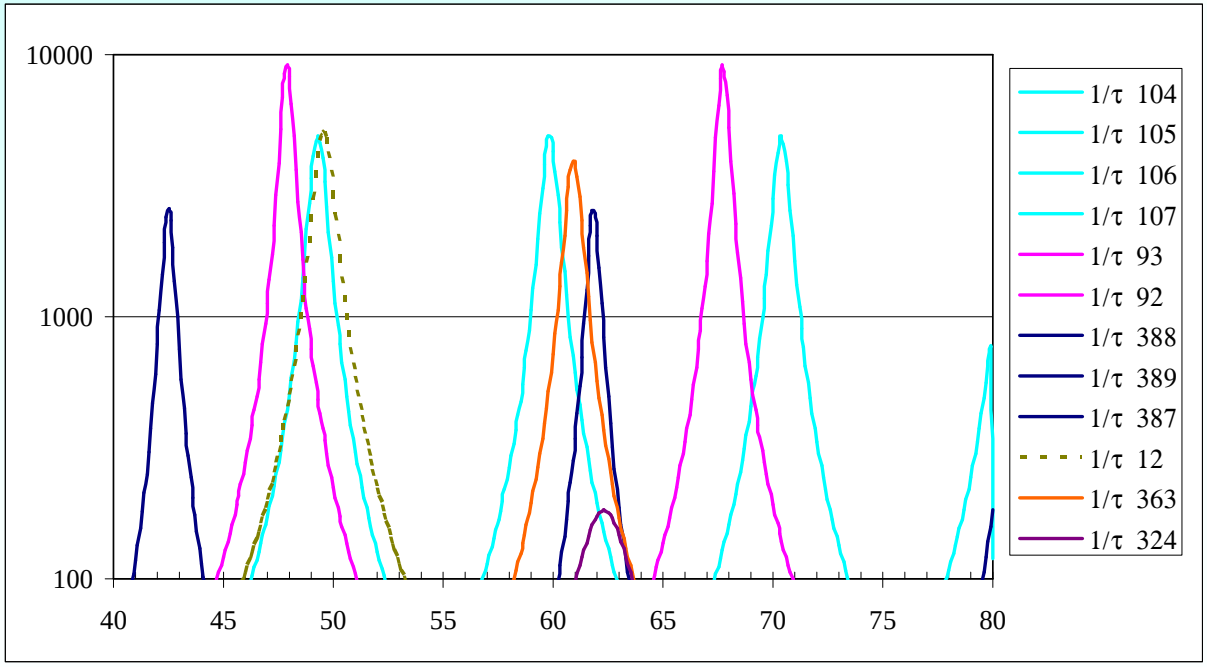


New cavity and HOM tuning

HOM spectrum already characterized in lab

3 machine shifts (8 x 3 hurs) dedicated to find the proper reference temperature setting

330 mA accumulated after 36 hours (vacuum conditioning). Still vacuum interlock at the beam dump – full reflected power.



- ✓RF booster and storage ring plants' reliability is generally good
- ✓Aging troubles : maintenance's strengthening is required
- ✓Upgrade of the RF storage ring components is going on
- ✓IOT tubes: the experience of our TH 793-1 installation could not confirm neither deny the reliability of these tubes for CW scientific application
- ✓Up to now we could not increase the total RF power delivered to the beam. More RF power is urgently needed!