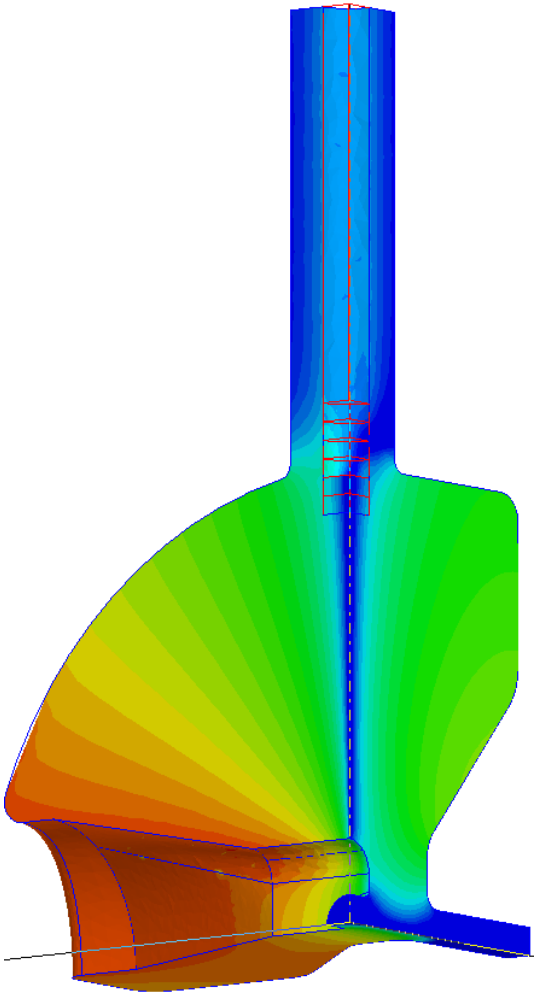
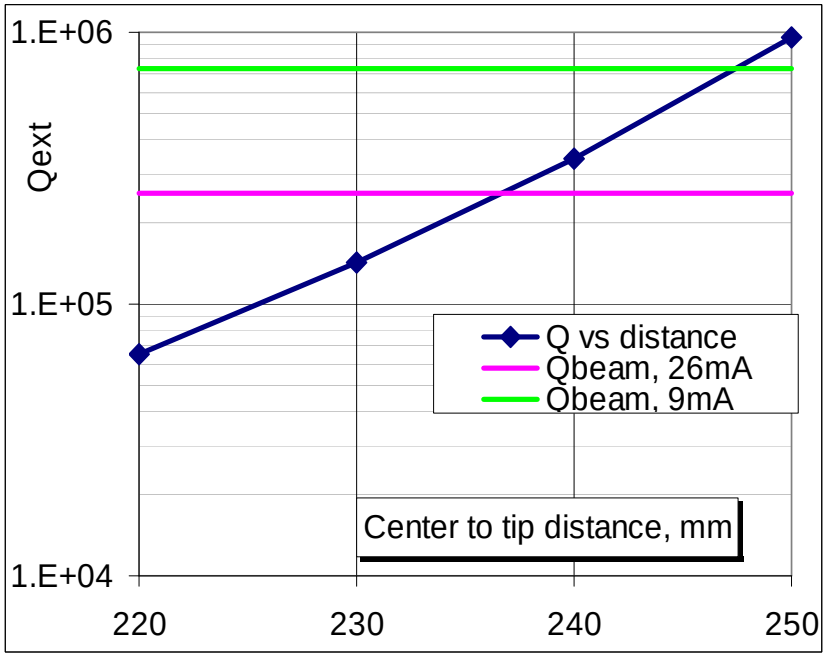
Power Coupler design for Superconducting Spoke cavities.

Originally 26 mA, 1 msec beam, 1.5 msec RF pulse, 10Hz operation



Magnetic fields in 1/8 of the Single Spoke Cavity. β=0.22 with 79mm port.

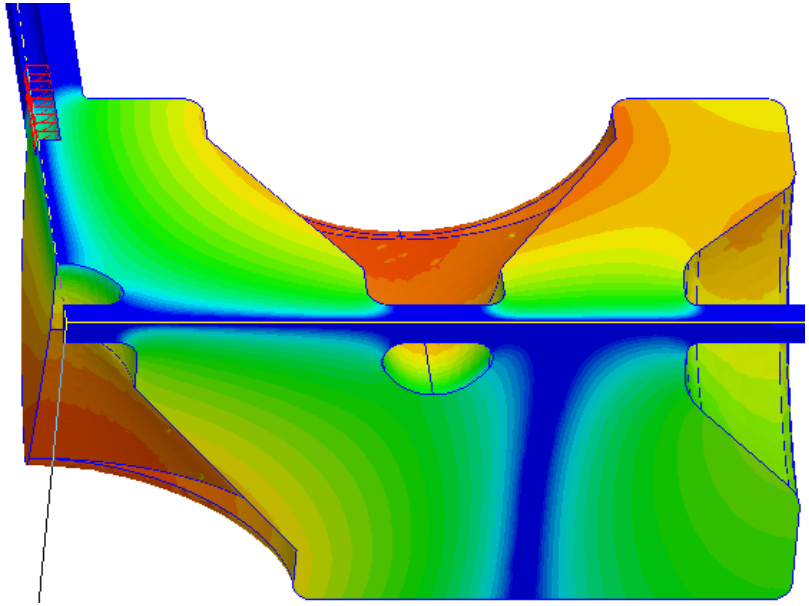
1 Spoke	mm	F, MHz	Q	U, V	W,J	cavit	tip	G	R/Q
b=0.22	220	323.967	65612	1.39E+06	3.9	4.8	12.70	83.7	240.1
Rs									
5E-08	230	323.977	141322	1.39E+06	3.9	4.8	5.89	83.7	240.2
0.002									
	240	323.983	345182	1.39E+06	3.9	4.8	2.40	83.8	240.2
Phase									
30	250	323.985	959104	1.39E+06	3.9	4.8	0.84	83.7	240.2
		Qbeam	256189						



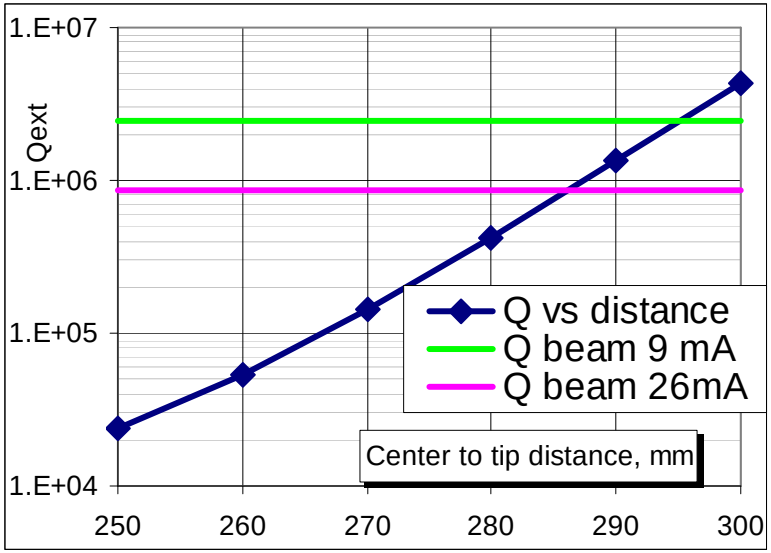
Triple Spoke Cavity. β=0.62.

Rs	mm	F, MHz	Q	U, V	W,J	cavit	tip	G
	260	324.057	53712	1.06E+07	100.1	87.3	688.4	116.8
5E-08	270	324.073	141996	1.06E+07	100.1	87.2	238.9	116.8
0.002								
	280	324.08	417764	1.06E+07	100.0	87.2	85.4	116.8
30	290	324.082	1342758	1.06E+07	100.0	87.2	25.9	
								R/Q
	300	324.83	4382200	1.06E+07	100.0	87.2	7.6	553.2
		Q, 26mA	851799					

9.3 MeV per cavity. Maximum pulsed power is 240 kW, average power is 3.6 kW.

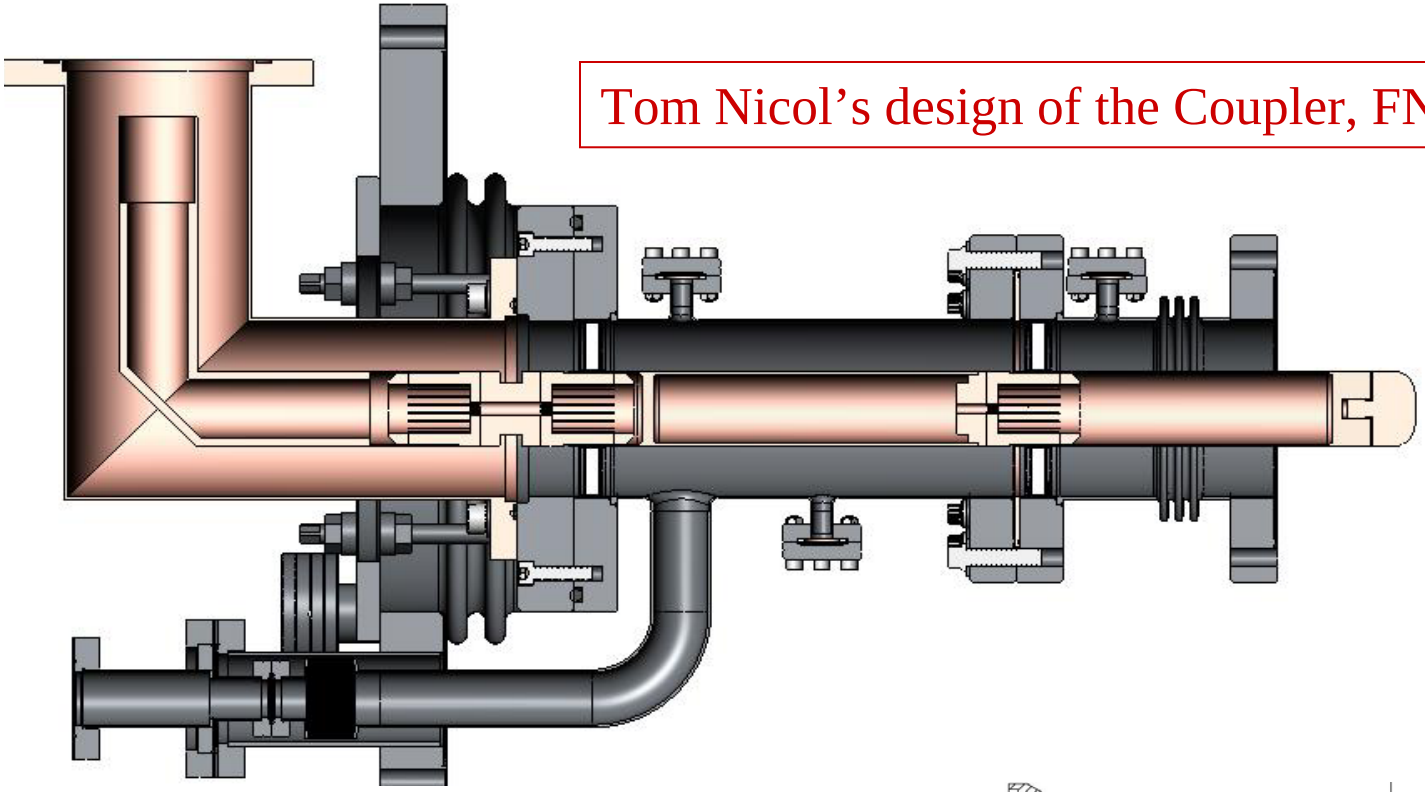


1/8 of the Triple Spoke Cavity. β=0.62 with 79mm port.



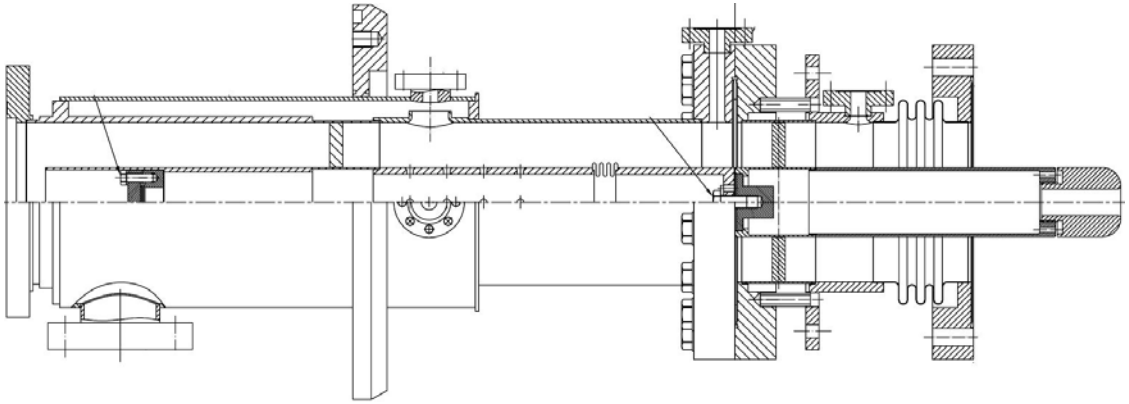
Mechanical design of the Power Coupler.

Tom Nicol's design of the Coupler, FNAL



Two planar ceramic windows, L/4 apart. Standard connectors

AMAC design based on FNAL design



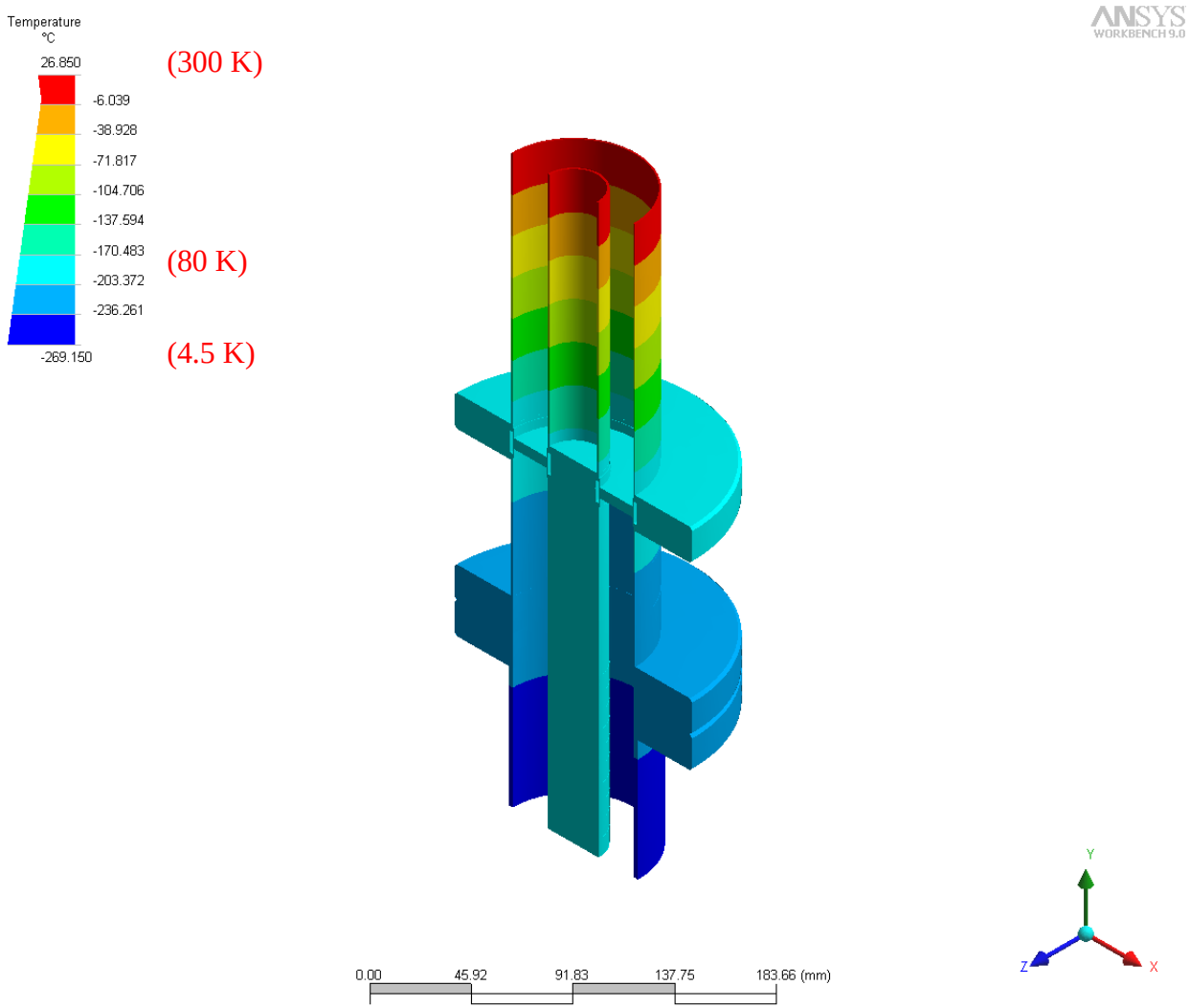
Summary of results. T. Nicol

Case	T at tip (K)	Q at 4 K (W)*	Q at 80 K (W)*	Q at 300 K (W)* (outer)	Q at 300 K (W)* (inner)	RF power (W)
1	300	1.17	5.52	0.32	6.14	0.23
2	222	1.17	3.31	0.70	3.54	0.23
3	148	1.17	1.13	1.07	0.99	0.23
4	142	1.17	0.96	1.10	1.03	0.00
5	93	0.67	2.37	1.46	1.35	0.23
6	94	1.00	3.49	2.92	1.34	0.23

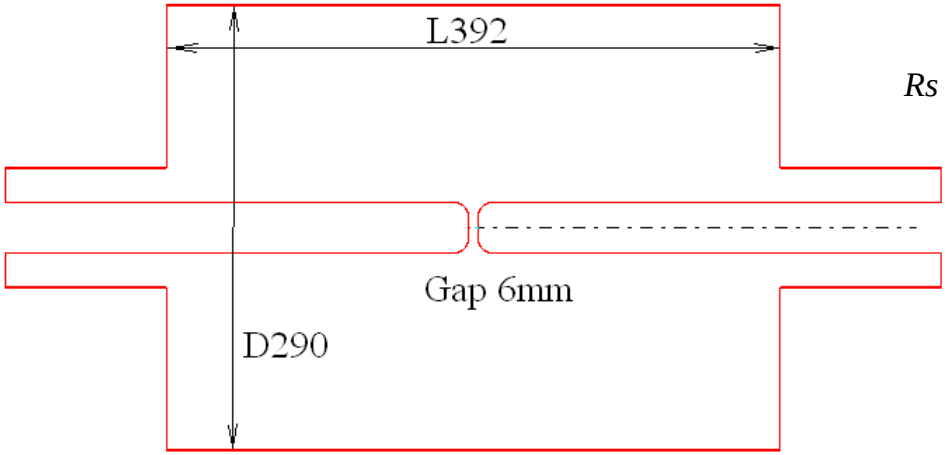
1	Solid copper center conductor from 300 K to 80 K.
2	Solid stainless steel center conductor from 300 K to 80 K.
3	Hollow stainless steel center conductor from 300 K to 80 K.
4	Same as 4, with RF power set to 0.
5	Same as 3, with 80 K intercept moved to ceramic window flange.
6	Same as 5, with stn stl tube sections increased to 1 mm (from 0.5 mm).

*: Static heat loads are due to conduction only.

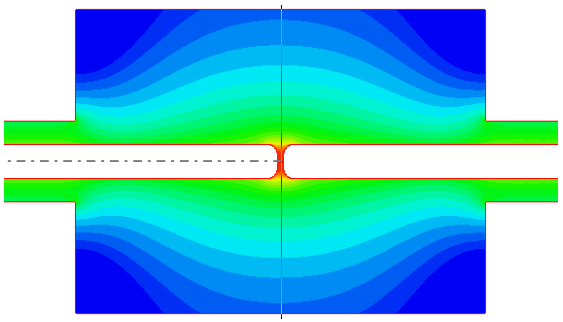
Typical resulting temperature plot (case 6). T. Nicol.



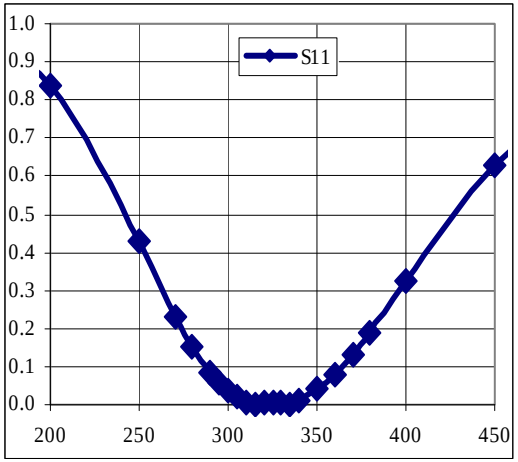
Coaxial 325 MHz Power Coupler Test Station.

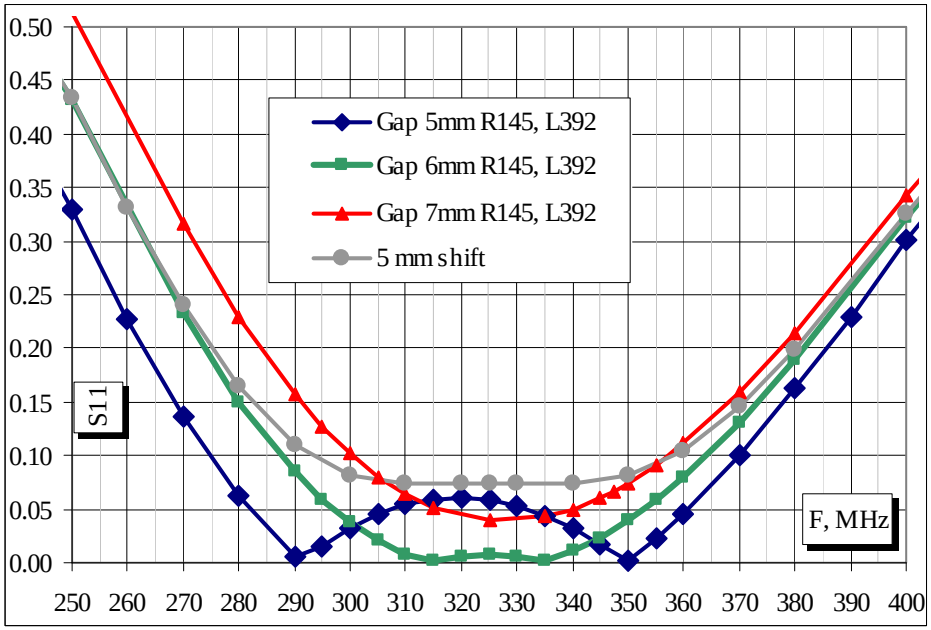


$$Rs = \sqrt{\frac{\pi f \mu_0}{\sigma}}$$



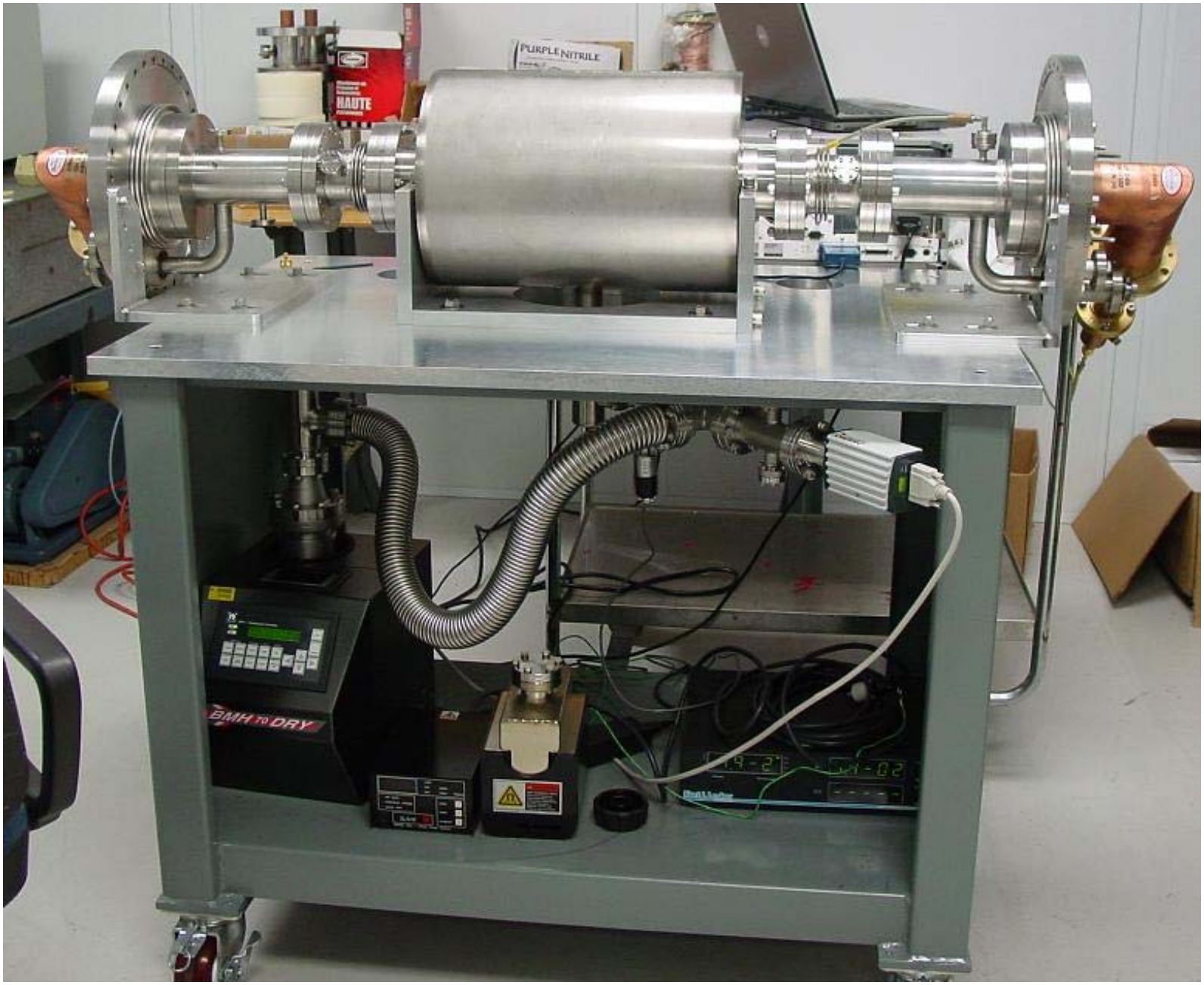
F=	3.25E+08	SSσ=	0.0342		Cuσ=	0.0047	
Surface	P, W	S, m^2	H^2	Rs	Ploss, W		Ep, kV/m
Can	30	0.477	0.915	0.0342	0.01562	0.0005	25
Inner conc	30	0.0648	5.07	0.0047	0.01192	0.0004	3.9
Can, 1%	2000			0.0342	1.04166		2041.241





Power loss in vacuum chamber walls 1 W for 2 kW transmitted power. In central conductors of the couplers each 0.8 W.

Test station. Vacuum chamber and pumping station.



Preparation steps.

- Assembling of the Coupler Power Processing Station in IB3. Done.

- Low power measurements of the 2 couplers assembled to chamber in the test station. IB3. Done.

- Vacuum check in IB3. Done.

- High power processing chamber cleaning in MP9 (and baking IB4). Assembling work done in A0. 1st pair of coupler are not baked. 2nd pair is baked 150C, 48h in A0.

- Cleaning of the all parts of the pair of couplers. MP9. Cleaning and other preparation work done in A0.

- Assembling of the cold parts to vacuum chamber in the class 10 clean room. MP9. Done in A0.

- Assembling of the warm parts in test station in the class 3000 clean area. Low power RF measurements. MP9 or IB4. Done in MP9.

Power processing steps.

- Connecting to high power lines. Connecting diagnostics. MDB:

2 temperature sensors per coupler

3 e-probes per coupler

Forward and reflected power signals.

Vacuum sensor.

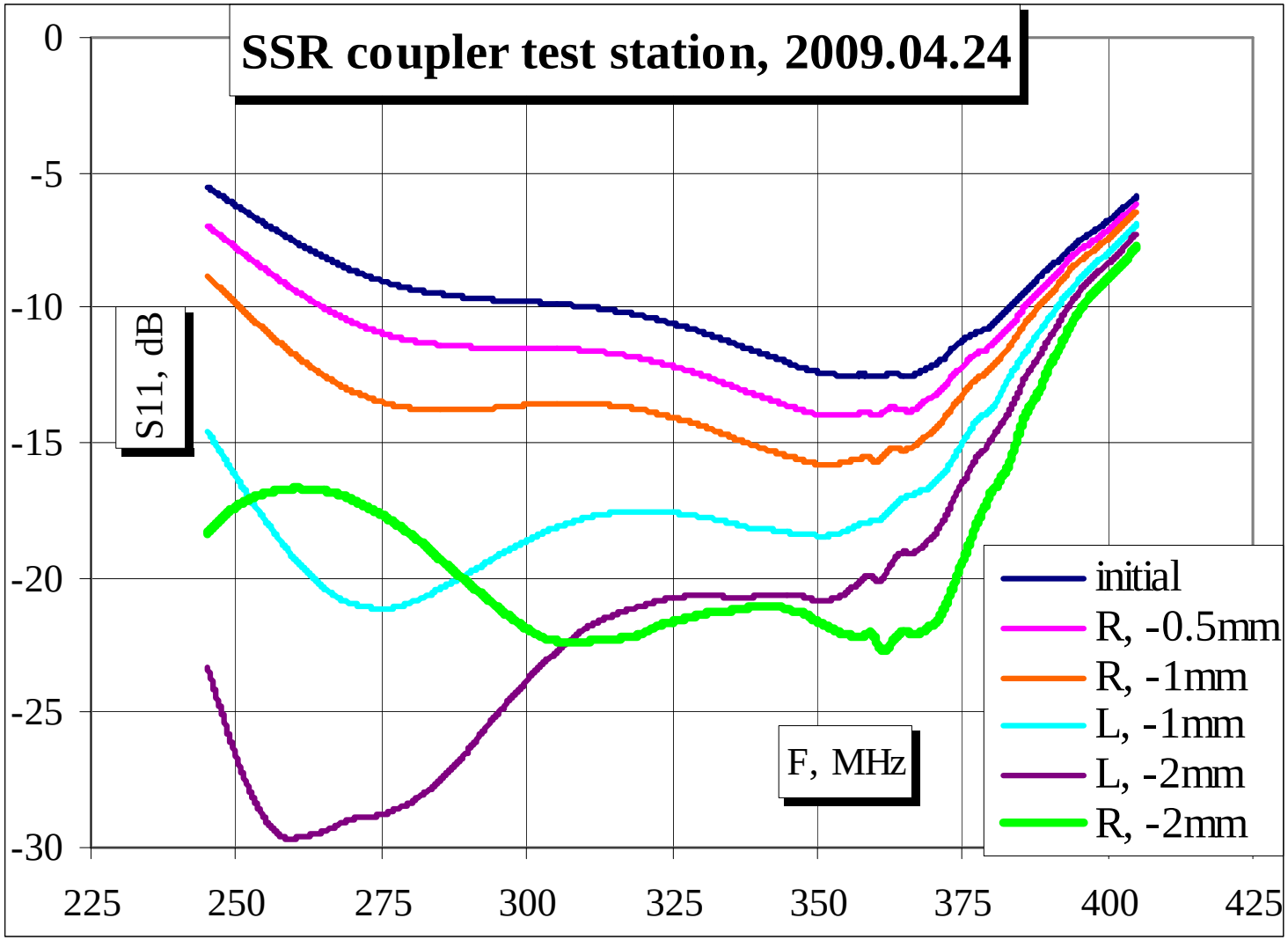
- High power processing range 5 – 500 kW in travelling wave regime:

Start with Pulse length 20 μsec and power 5 kW. Look on vacuum signals <5e6 Tor and e-probe signals <0.1 mA, reflected power limit (20% of forward power) and windows temperatures. After improving vacuum better than 5e-7 Tor increase power with steps 1-2 dB up to 500 kW.

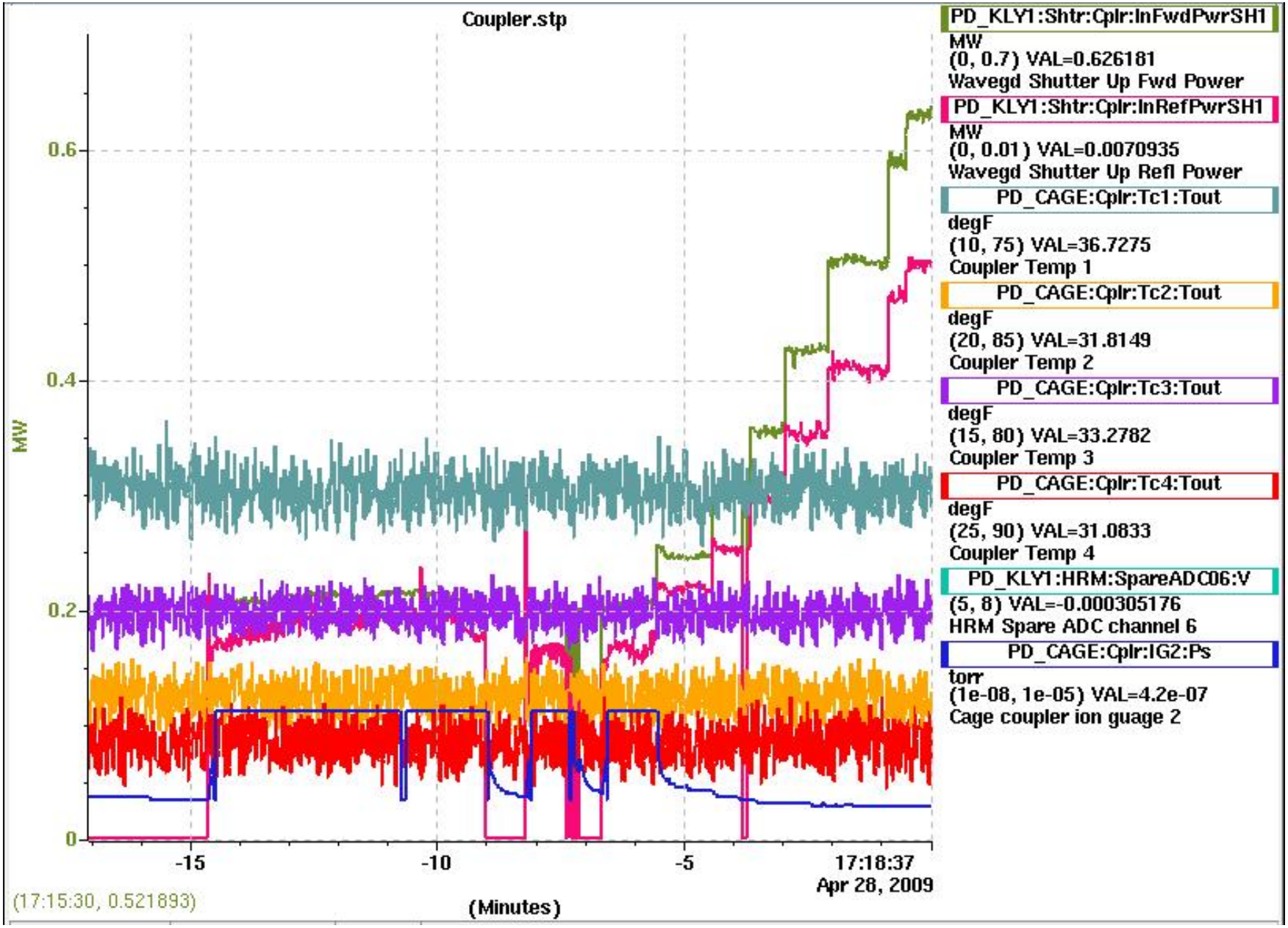
Repeat previous step with pulse length 50, 100, 200, 400, 800, 1500 and 3000 μsec.

- High power processing range 5 – 300 kW in standing wave regime:
Start with Pulse length 20 msec and power 5 kW. Look on vacuum signals <5e6 Tor and e-probe signals <0.1 mA. After improving vacuum better than 5e-7 Tor increase power with steps 1-2 dB up to 200 kW.
Repeat previous step with pulse length 50, 100, 200, 400, 800, 1500 and 3000 msec.
- Disconnect from diagnostics and power lines.
- Disconnect warm part in in the class 3000 clean area. MP9 or IB4.
- Disconnect cold parts in and install caps in class 10 area. Put to storage. MP9.

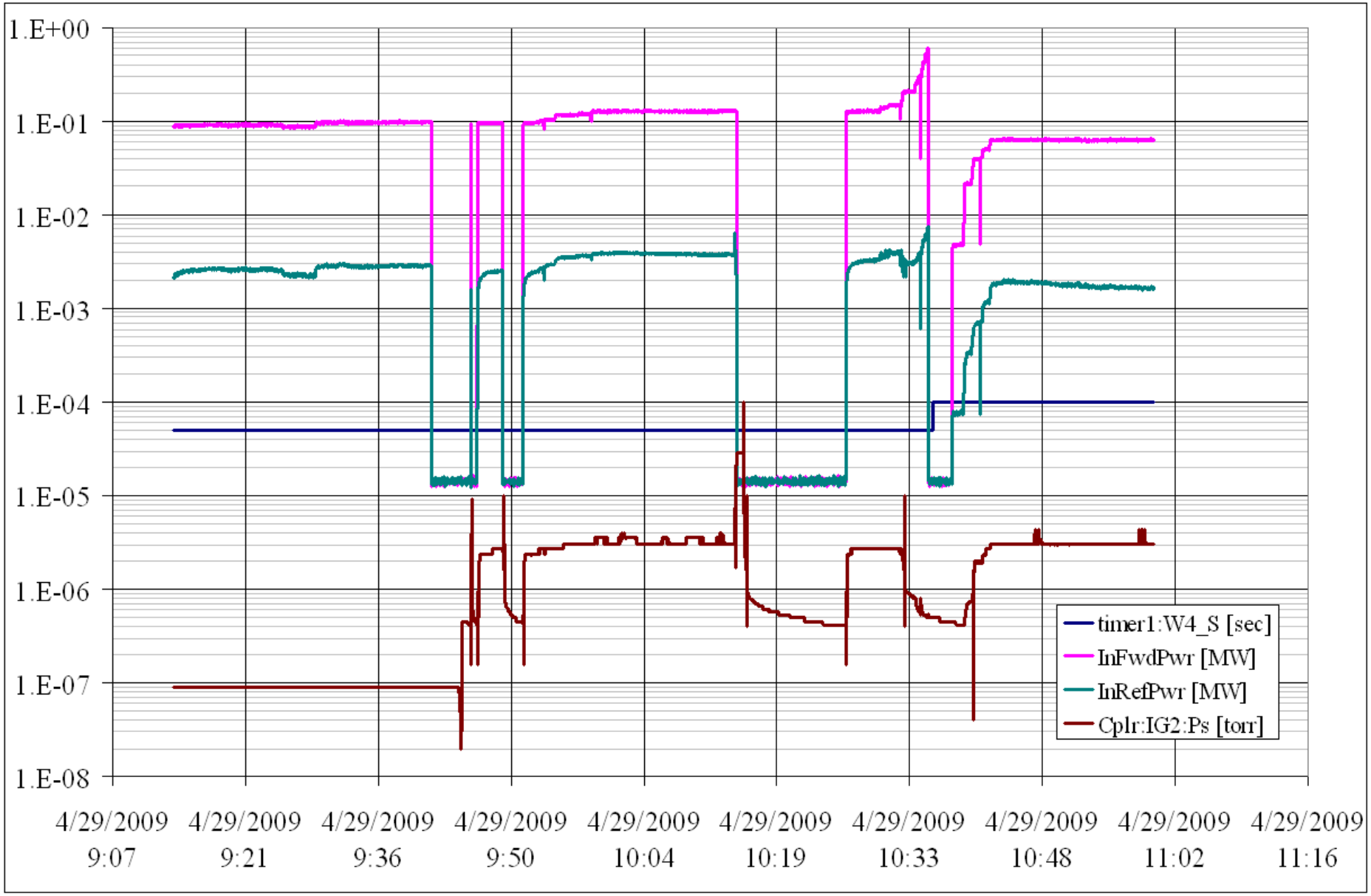
Adjusting gap between coupler tips.



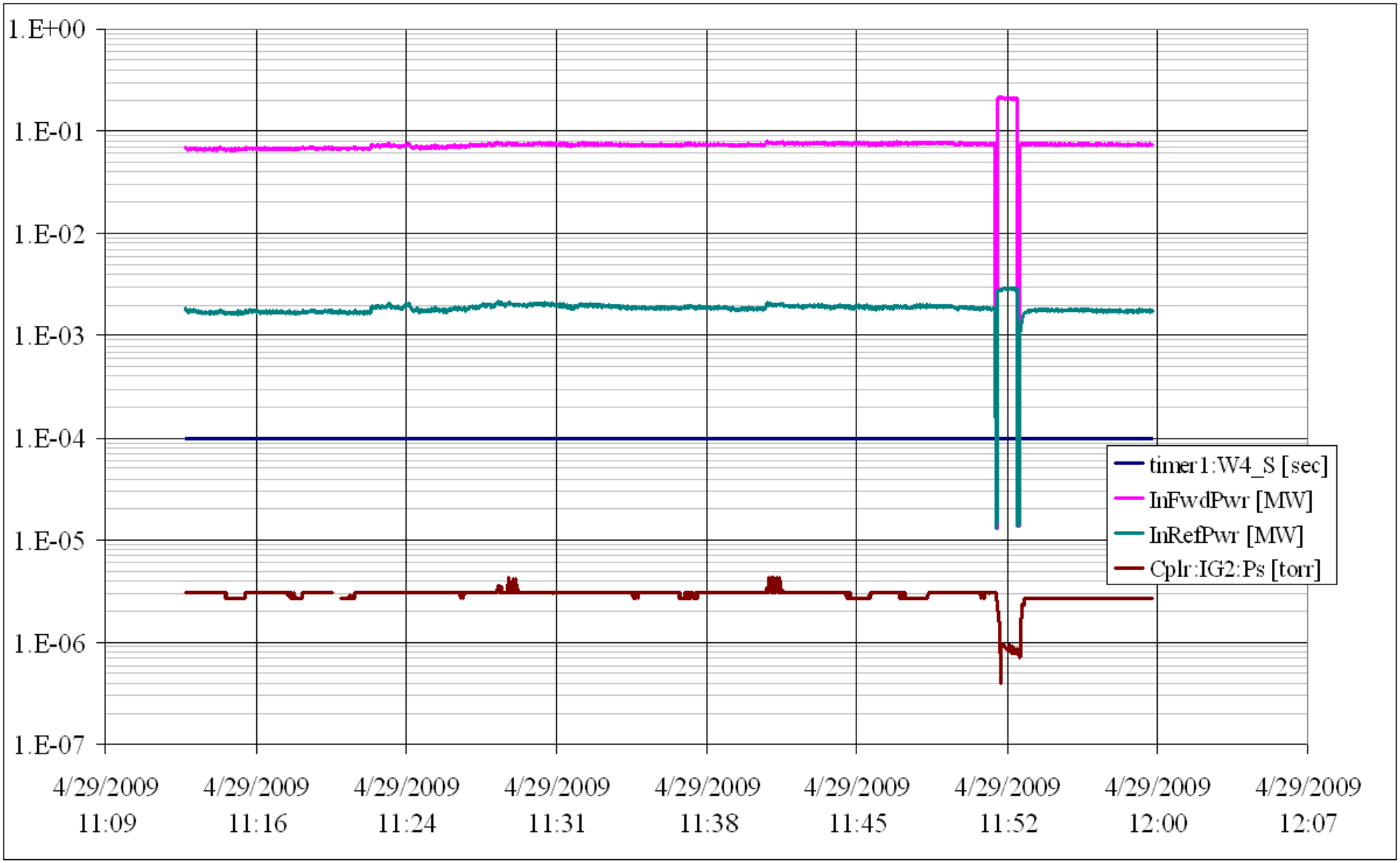
20 μsec pulse 1Hz Power processing finished in 9 hours.



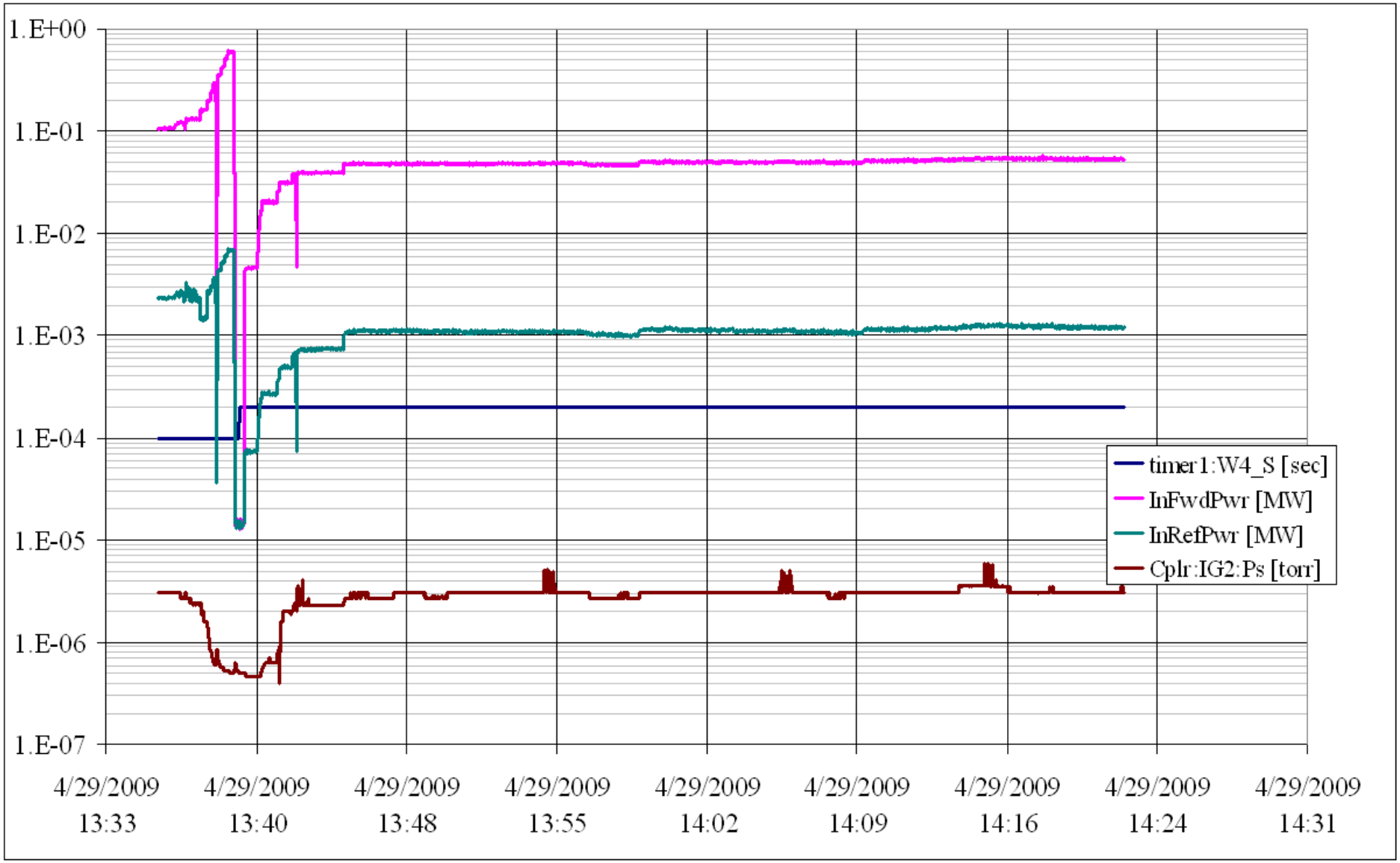
50 μsec pulse 1Hz Power processing finished in 2 hours. Processing speed limited by vacuum 3e-6 due to multipactoring.



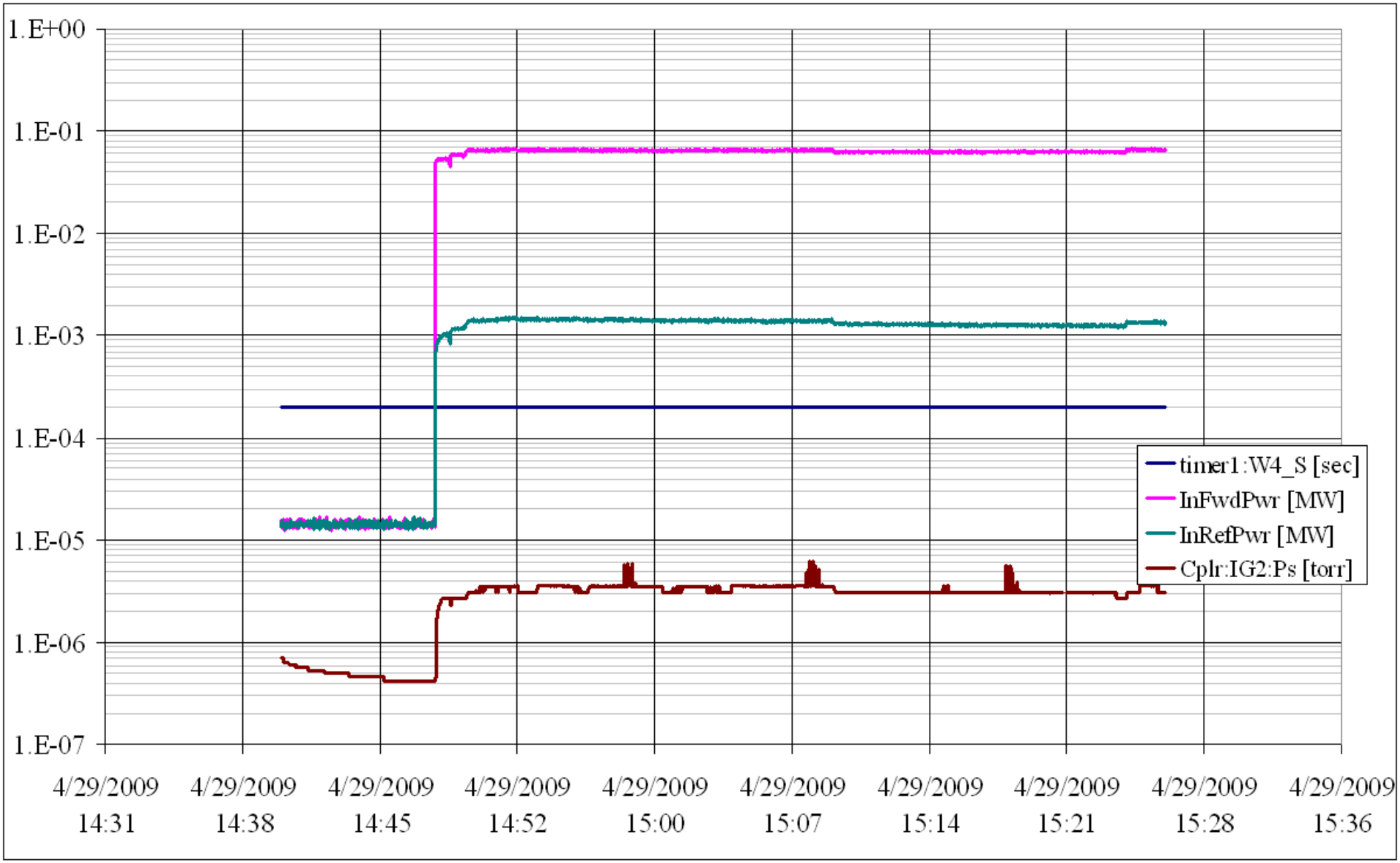
100 μsec pulse 1Hz Power processing finished in 1.5 hours.



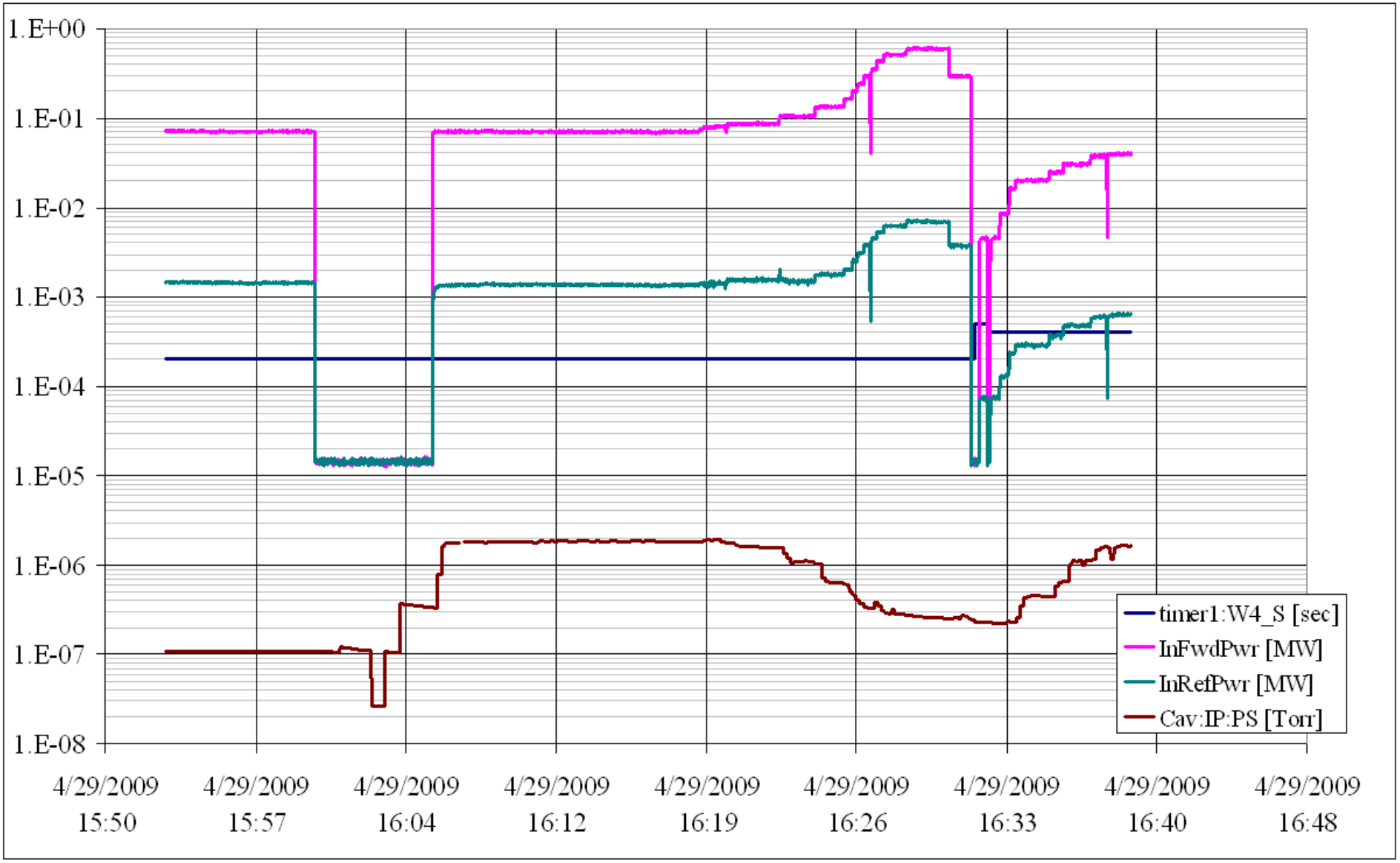
100 μsec pulse 1Hz Power processing finished in 1.5 hours. Processing speed limited by vacuum 3e-6 due to multipactoring. Multipactoring disappear above 120 kW.



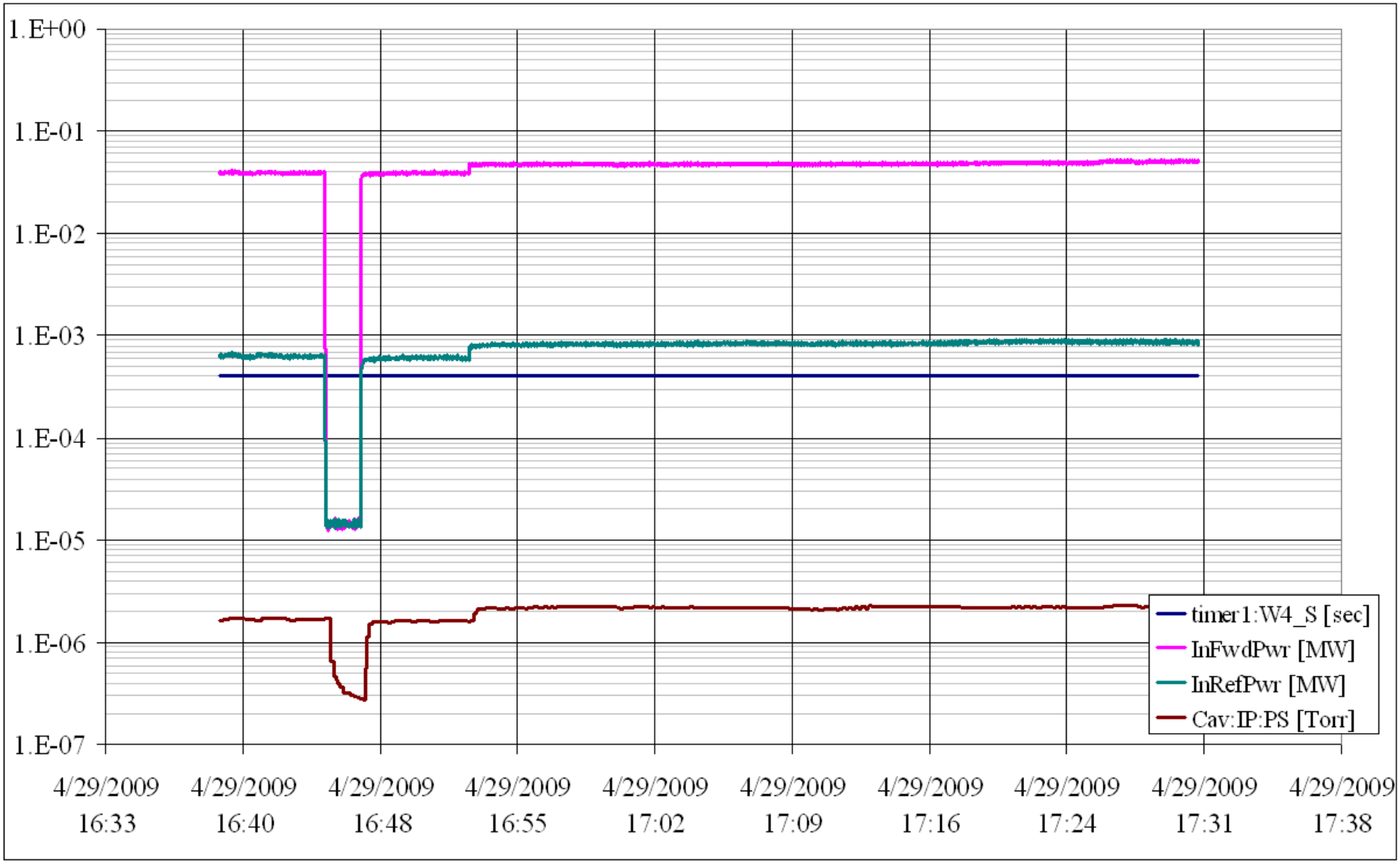
200 μsec pulse 1Hz Power processing finished in 3 hours.



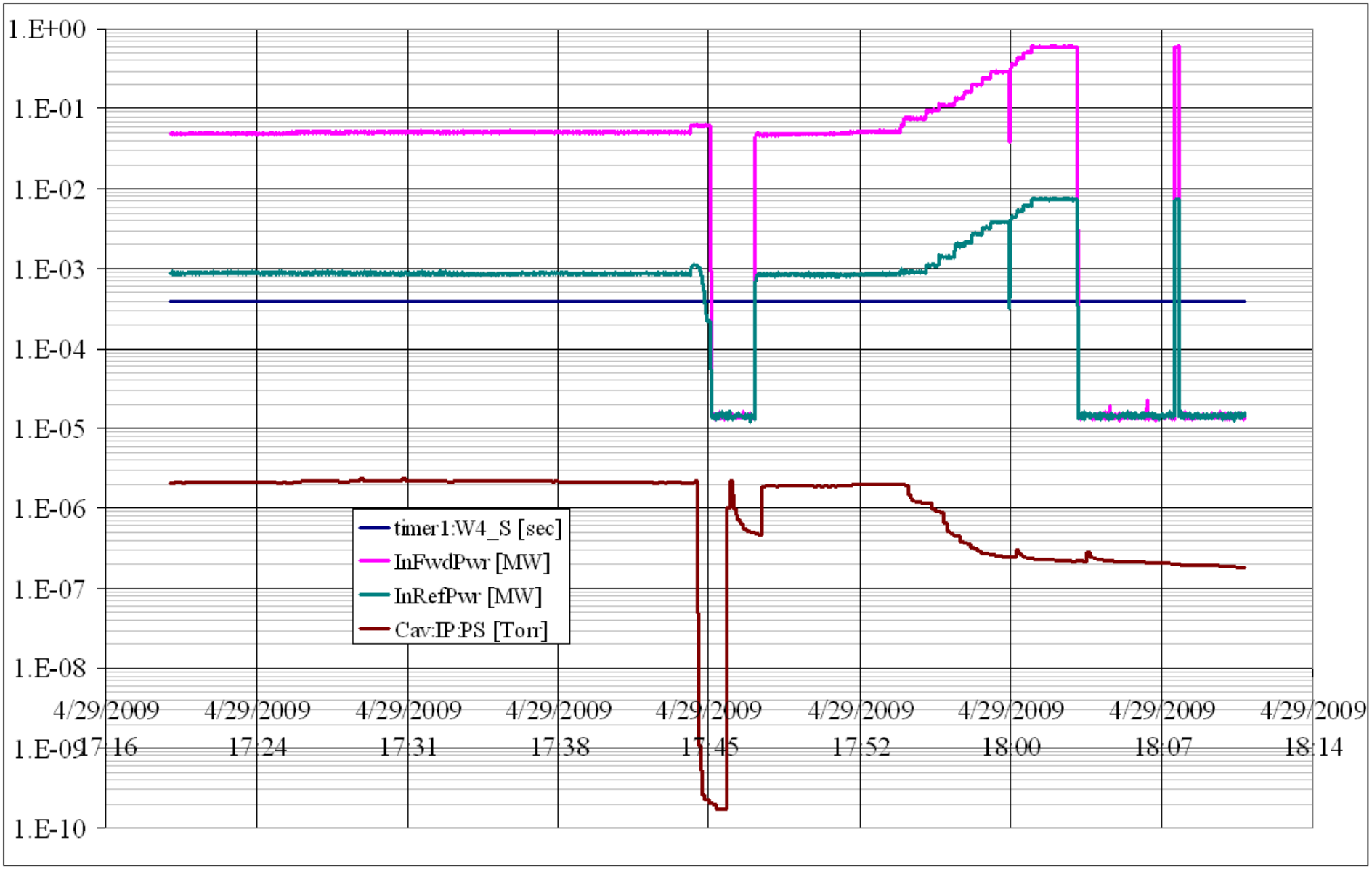
200 μsec pulse 1Hz Power processing finished in 3 hours. Multipactoring disappear above 110 kW.



400 μsec pulse 1Hz Power processing finished in 1.5 hours.



400 μsec pulse 1Hz Power processing finished in 1.5 hours. Multipactoring disappear above 80 kW.

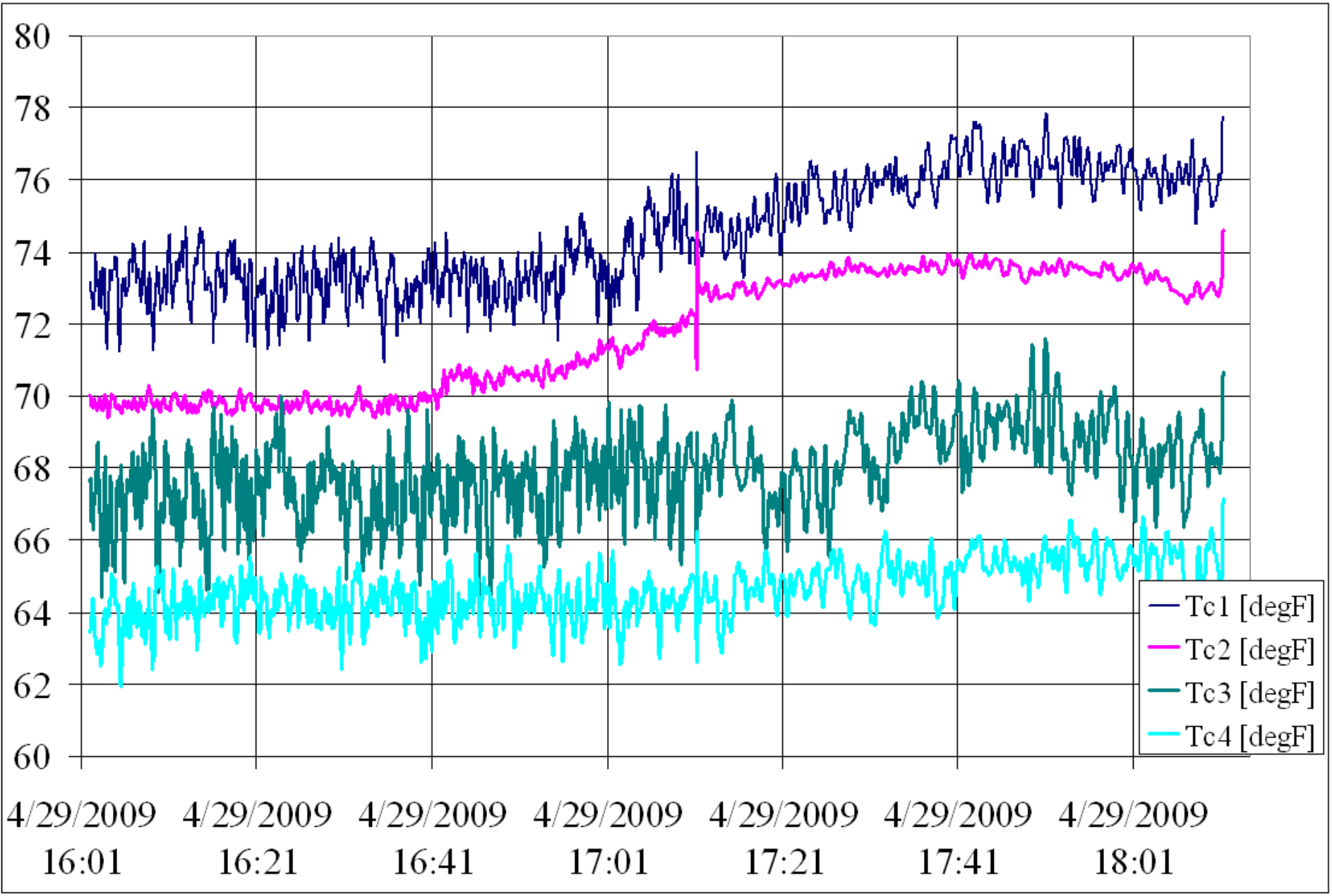


Summary of power processing of the 1st pair of the couplers. Multipactor is limiting factor.

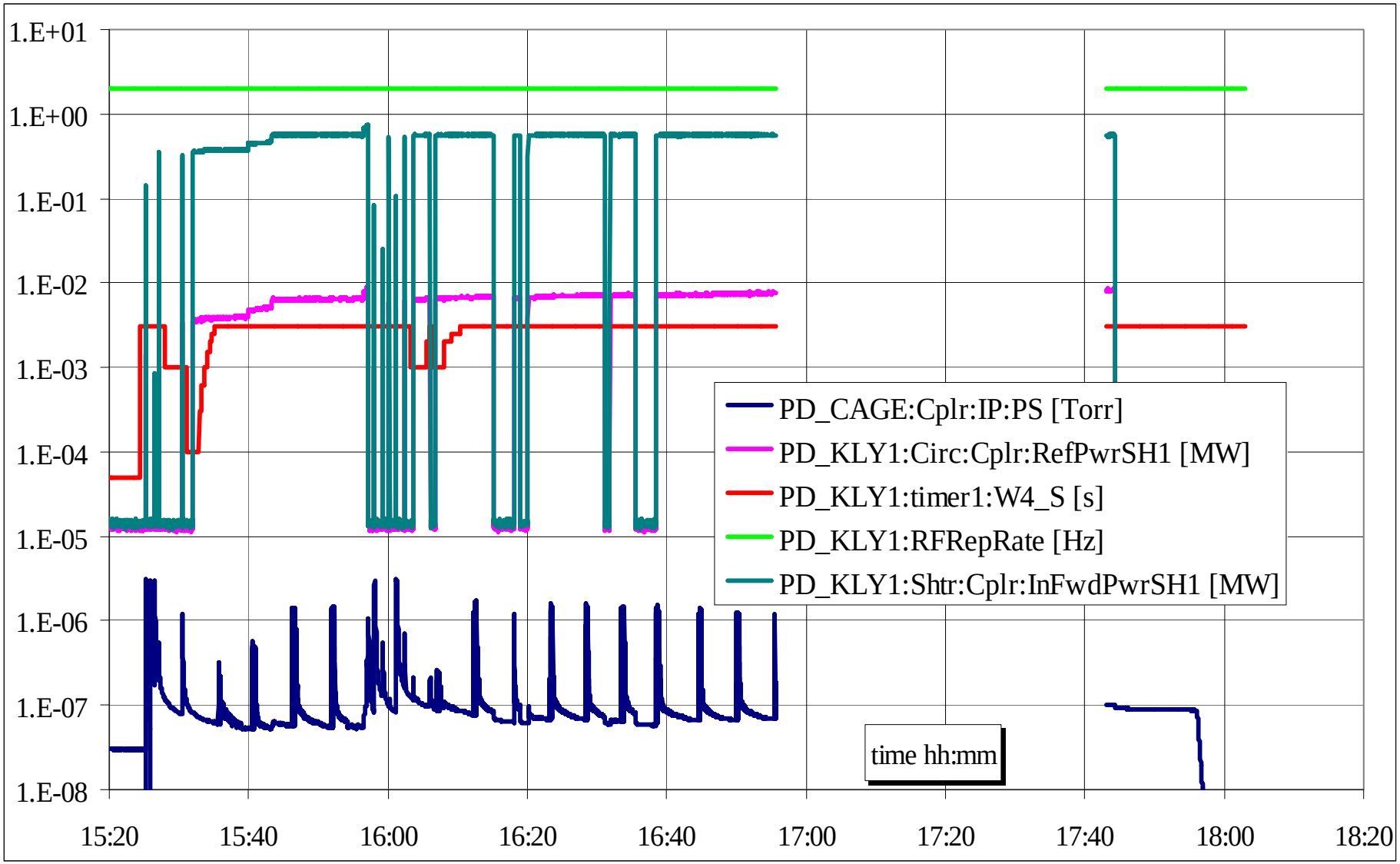
t, μsec	Pstart, kW	Pstop, kW	T, Hours
20	5	220	9
50	10	200	2
100	20	120	1.5
200	40	110	3
400	40	80	1.5
800	40	75	1.5
1500	40	75	1.5
3000	40	70	2

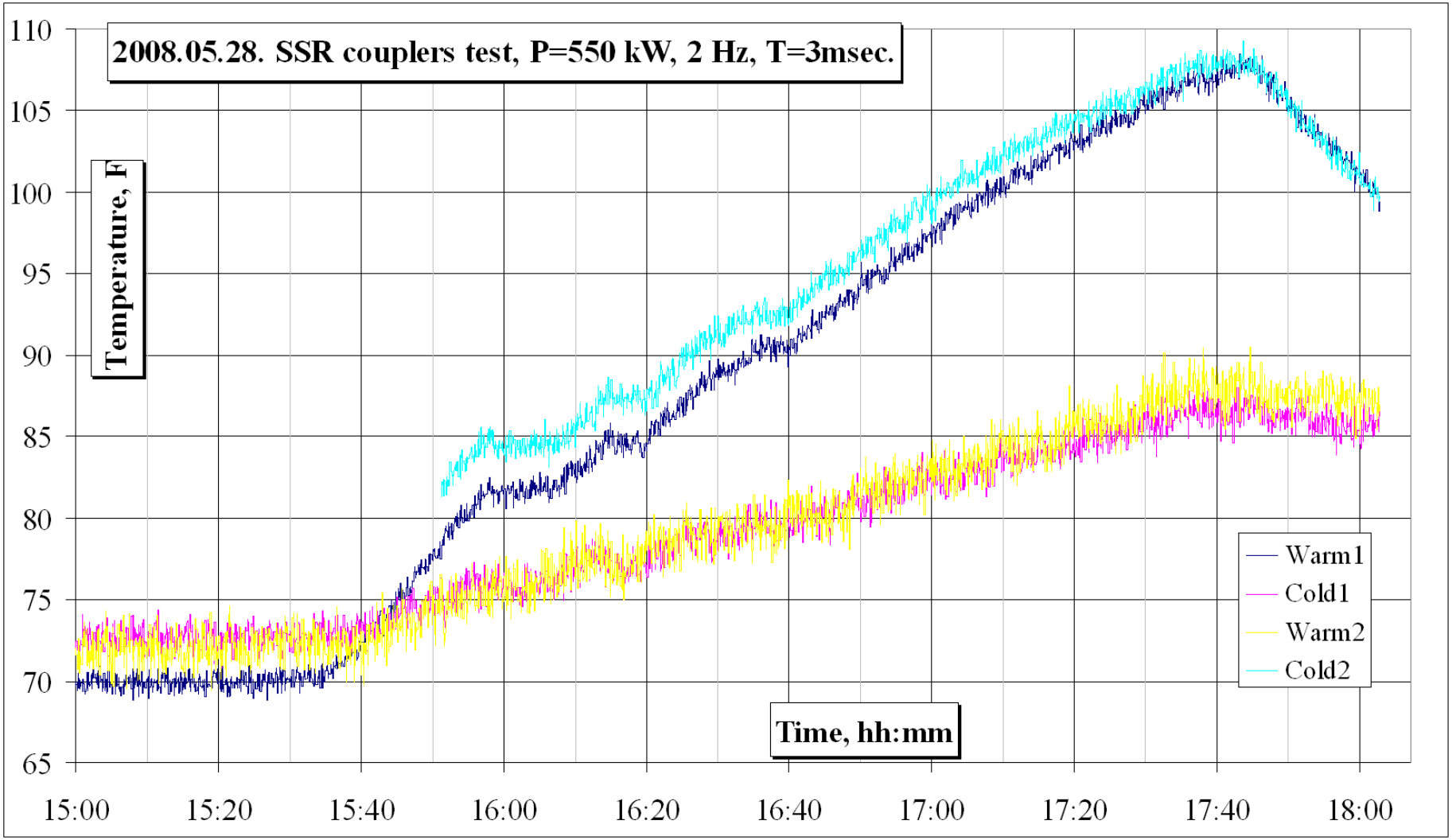
Ppeak, W	Pulse, sec	F, Hz	Paver, W
550000	0.003	2	3300
600000	0.0004	1	240

400 μsec pulse 1Hz. Temperature in the windows of 1st coupler increased by 3F.



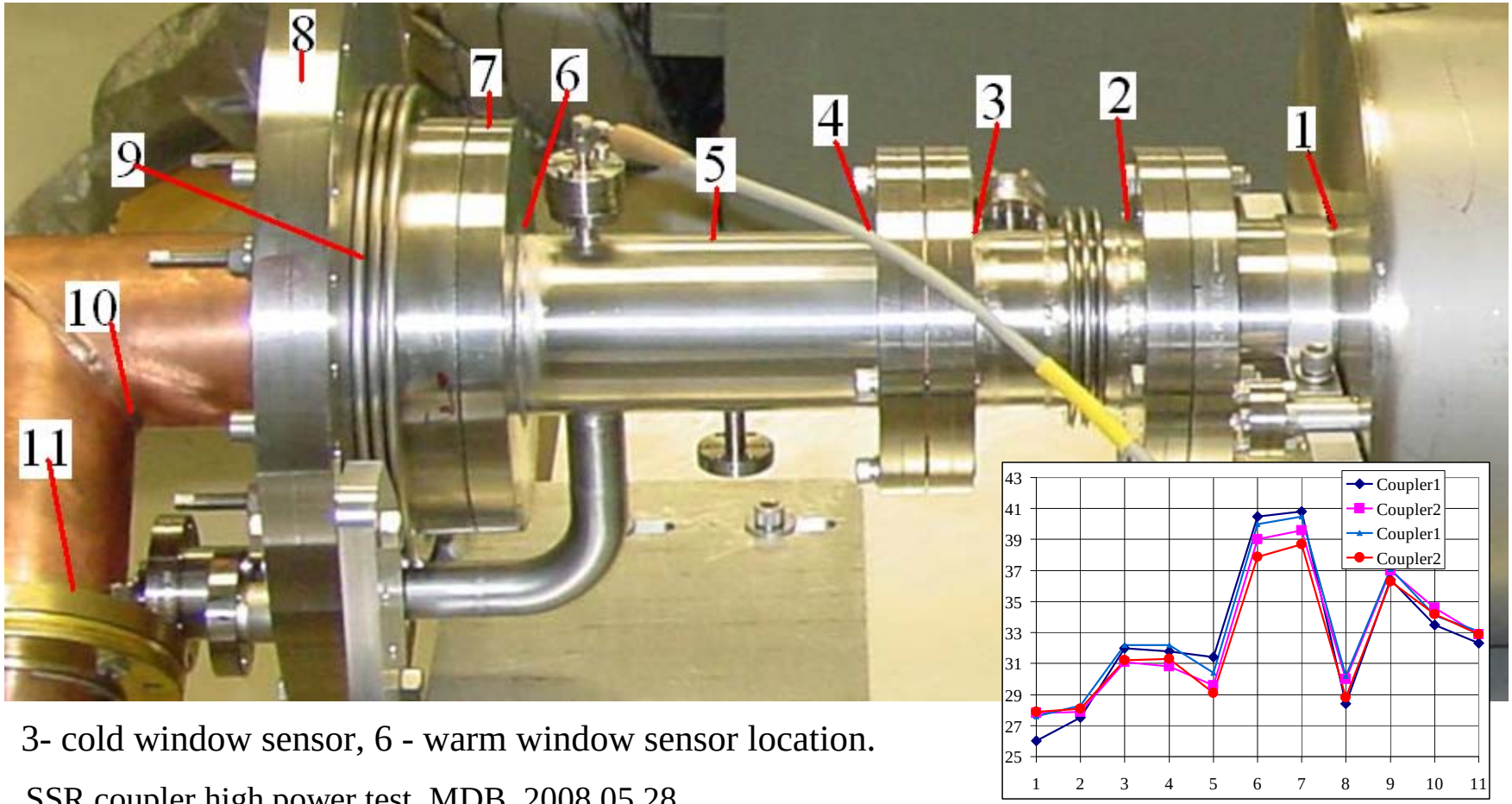
2009.05.28. 3 ms pulse 2Hz 550 kW power, average power 3.3 kW.





Temperature raised by 38F on Warm1 window flange in 2h10min. Gradient at the beginning was 0.6F/min and at the end 0.2F/min. Total dT~57F~36C maximum heating can be expected.

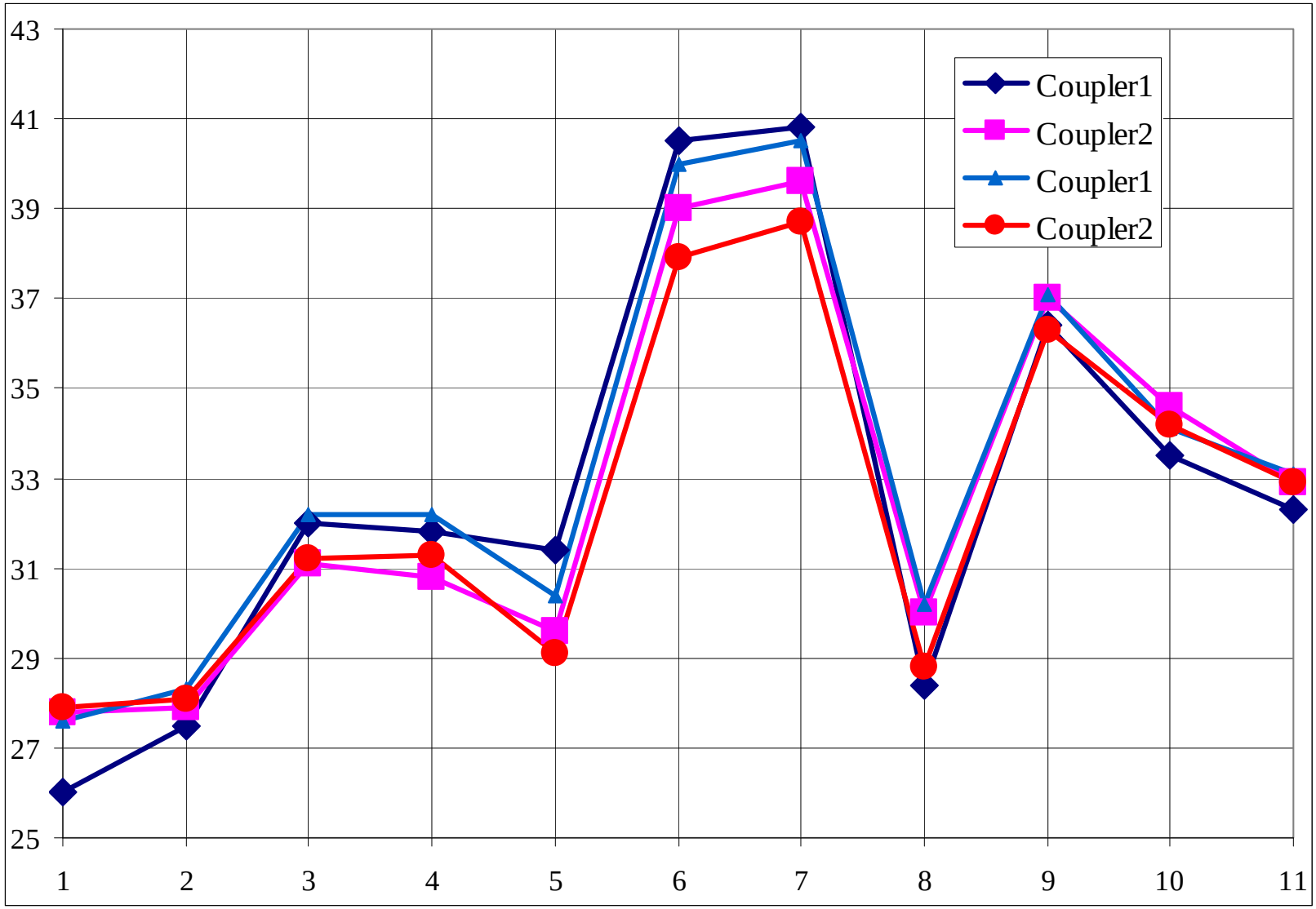
Map of the temperature measurement points.

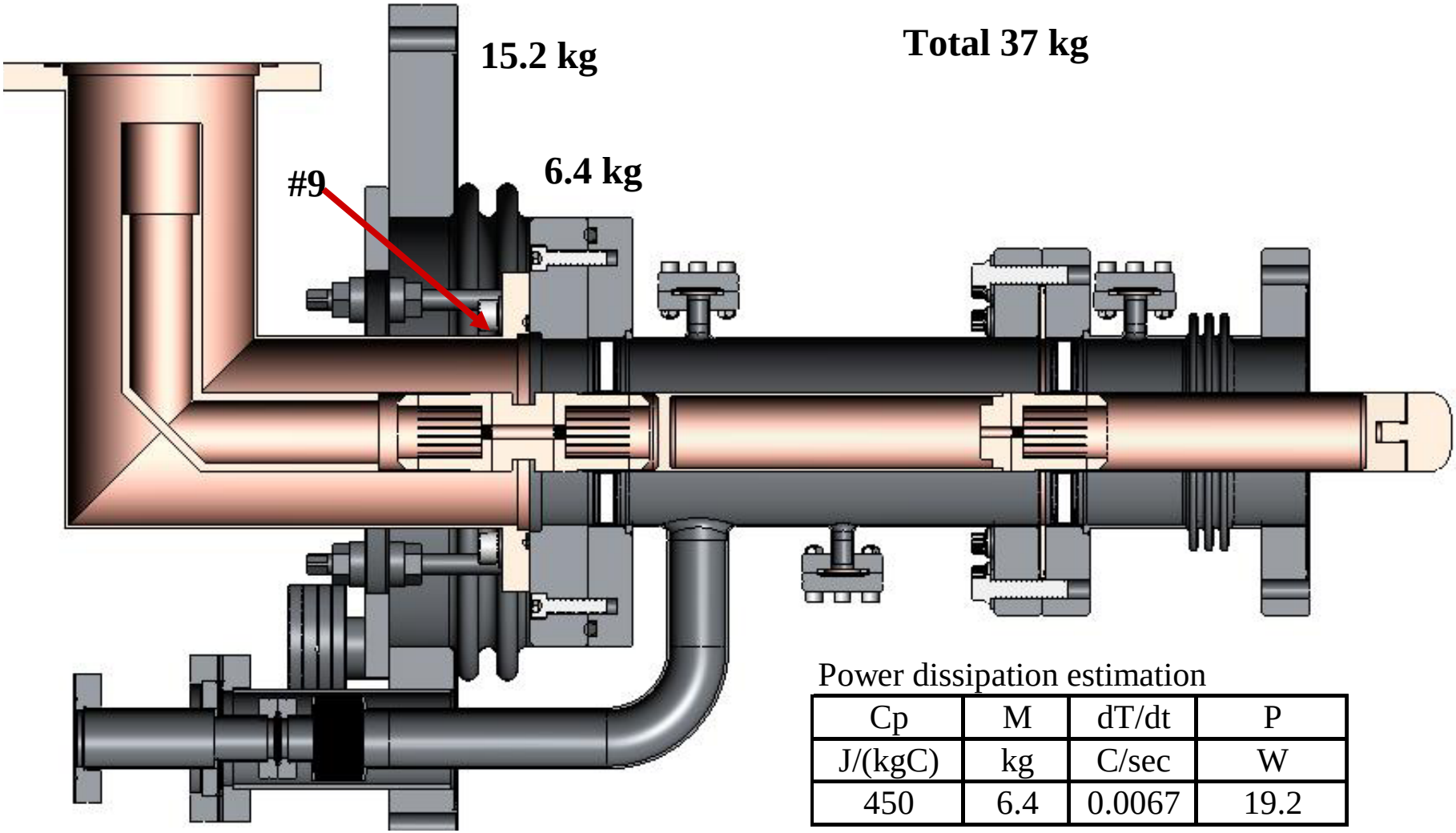


3- cold window sensor, 6 - warm window sensor location.

SSR coupler high power test. MDB, 2008.05.28.

# pos.	1	2	3	4	5	6	7	8	9	10	11	Time
Coupler1	26	27.5	32	31.8	31.4	40.5	40.8	28.4	36.4	33.5	32.3	5.45
Coupler2	27.8	27.9	31.1	30.8	29.6	39	39.6	30	37	34.6	32.9	5.48
Coupler1	27.6	28.3	32.2	32.2	30.4	40	40.5	30.2	37.1	34.1	33.1	5.52
Coupler2	27.9	28.1	31.2	31.3	29.1	37.9	38.7	28.8	36.3	34.2	32.9	5.55


43
41
39
37
35
33
31
29
27
25
1
2
3
4
5
6
7
8
9
10
11
Coupler1
Coupler2
Coupler1
Coupler2



Power dissipation estimation

Cp	M	dT/dt	P
J/(kgC)	kg	C/sec	W
450	6.4	0.0067	19.2

Power loss in coaxial waveguide with 2 windows.

Pf	Inner	Outer	Inner	Outer	Windows	Total
W	Losses	Losses	W	W	W	W
3300	0.0009	0.0014	2.97	4.62	0.15	7.74

SSR power coupler test and conditioning results:

Two coupler setup were conditioned in 25 hours .

Maximum peak power reached 1 MW in travelling wave regime, 2 Hz, 3 ms. Only several spars observed. Can be tested at higher power level.

Maximum average power 4.2 kW (2Hz, 3 ms, 700kW) during 2 hours.

3 hours additional test at 3.3 kW average power (2 Hz, 3 ms, 550 kW).

Worth multipactoring in power range 40-50 kW. But can be conditioned to vacuum 1e-7 Torr in 10 hours.
More than expected heating of the warm windows area. Probably bad RF connection there.

Two coupler conditioned and one of them can be installed to cavity SSR1-01 for a cold test.
Next set of two coupler assembled, baked 150C 48h and power conditioning started.
One of these couplers manufactured by AMAC under SBIR project.

1 mA CW operation with current acceleration pattern:

1. SSR1 cavity. Forward power P=1.2 kW is OK with existing Power Coupler design.

2. SSR2 cavity. Forward power P=3.6 kW is probably OK with existing design.

3. TSR cavity. Forward power P=9.3 kW is too much for existing design.
   Possible improvements of the existing design allows to reach 10-20 kW average power:

- Copper plating of the outer conductor
- Thermal intercept in the middle of the bellow to 4.5K
- Cooling of the central conductor with cold gas (Nitrogen).