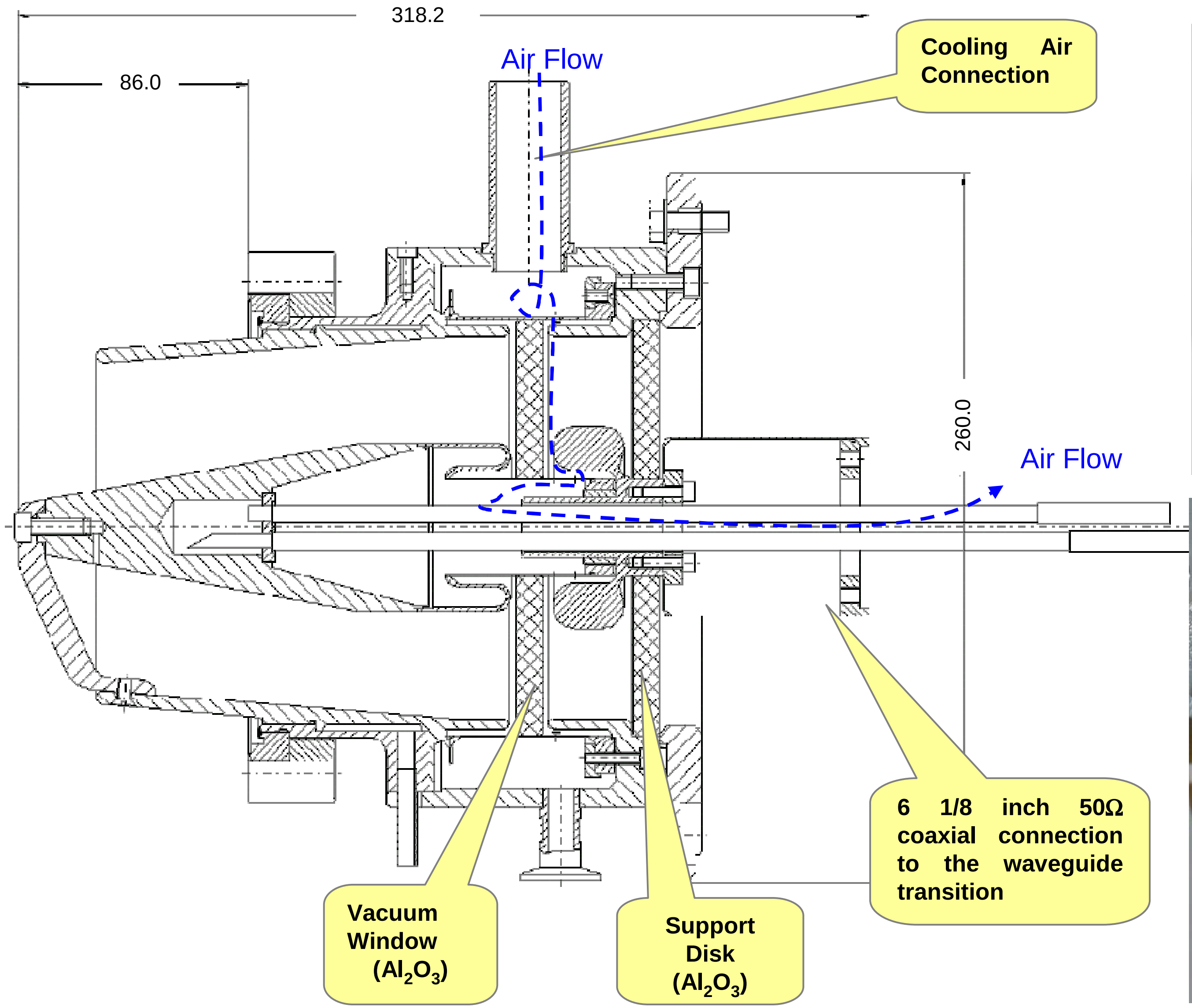
250-kW Upgrade of Cavity Couplers for PETRA-3

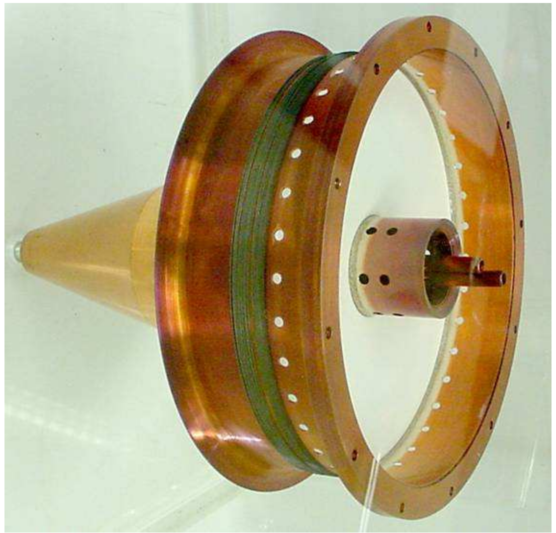
- Coupler Design and 35 years passed down Experience
- Traditional Pre-treatment and Conditioning Method
- Successful Improvements
- The Really Breakthrough
- Present State-of-the-Art
- Summary

Sectional Drawing of the PETRA Coupler



History and Facts

- Originally designed for DORIS-1 in 1972
- Nominal power 60kW, max. tested up to 140kW (once?)
- Modified for PETRA-1 1976 (mech. length reduced)
- At last 114 couplers were in Operation at HERA, PETRA-2, DORIS-3 and DESY-2; all operated at <90kW
- Most couplers could be operated save up to 100…120kW after a careful condition process.
- But some couplers failed already during the conditioning process at 50…70 kW.
- On the other hand very few couplers could be conditioned up to > 500 kW.



The vacuum window assembly remained unchanged since 1972

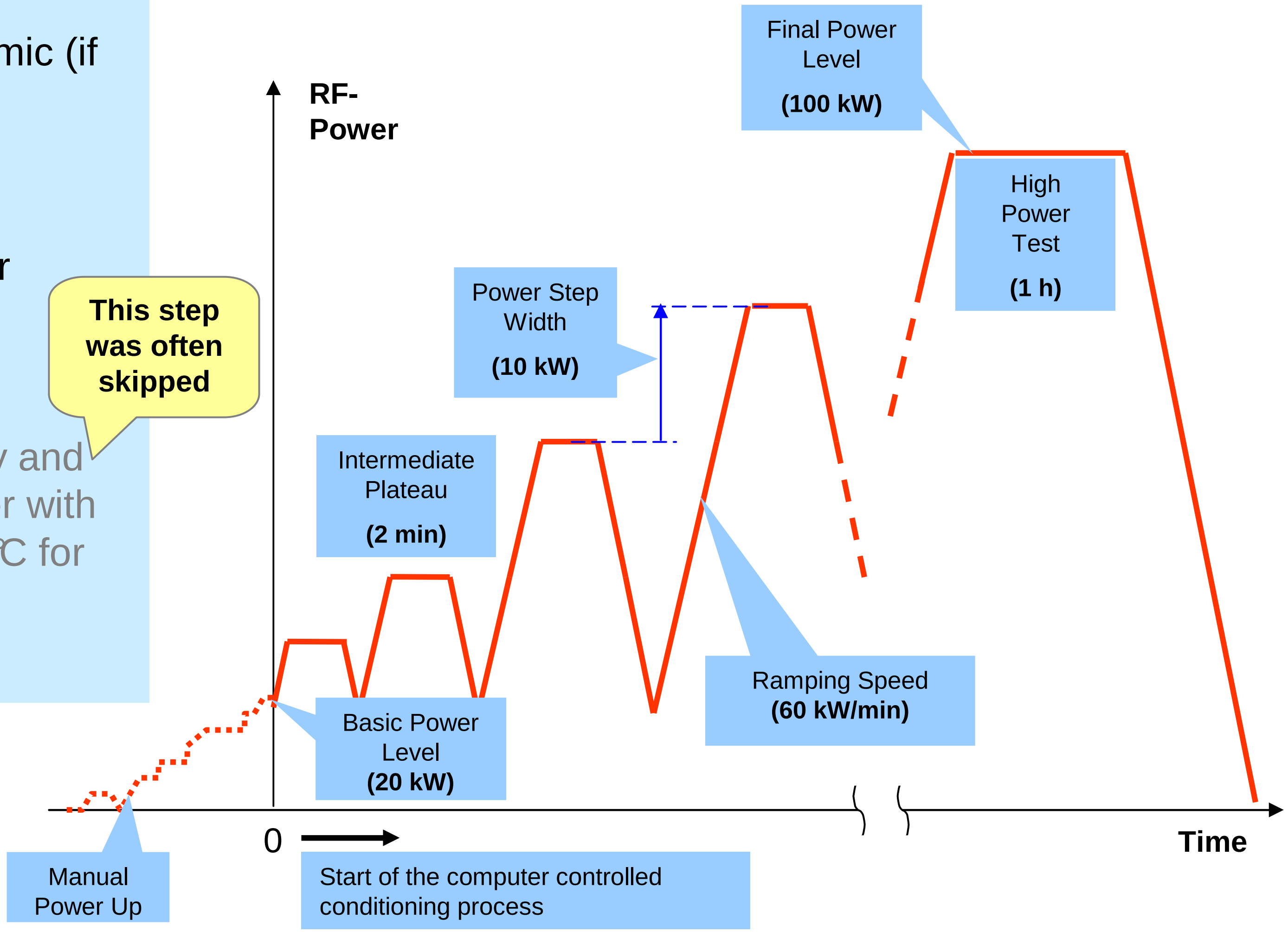
Traditional Pre-Treatment and Conditioning

Pre-treatment:

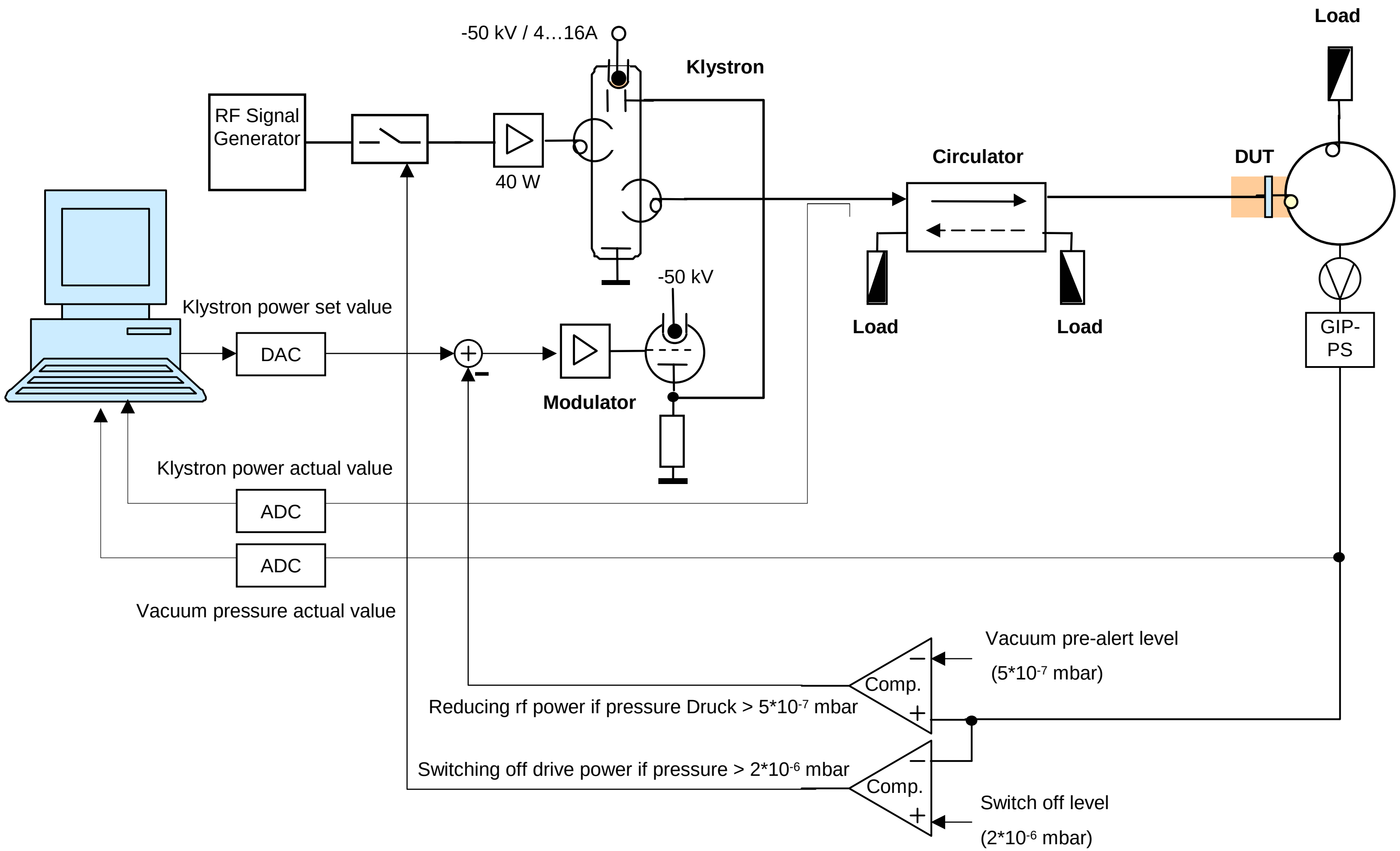
- Etching of the ceramic (if required)
- Flushing first with demineralised water followed by alcohol or isopropanol.
- Drying
- Installing to a cavity and baking cavity together with coupler at about 200℃ for one day.
- Conditioning

This step was often skipped

Diagram of RF Power Conditioning



Coupler Test Station



“Success” of Coupler Conditioning

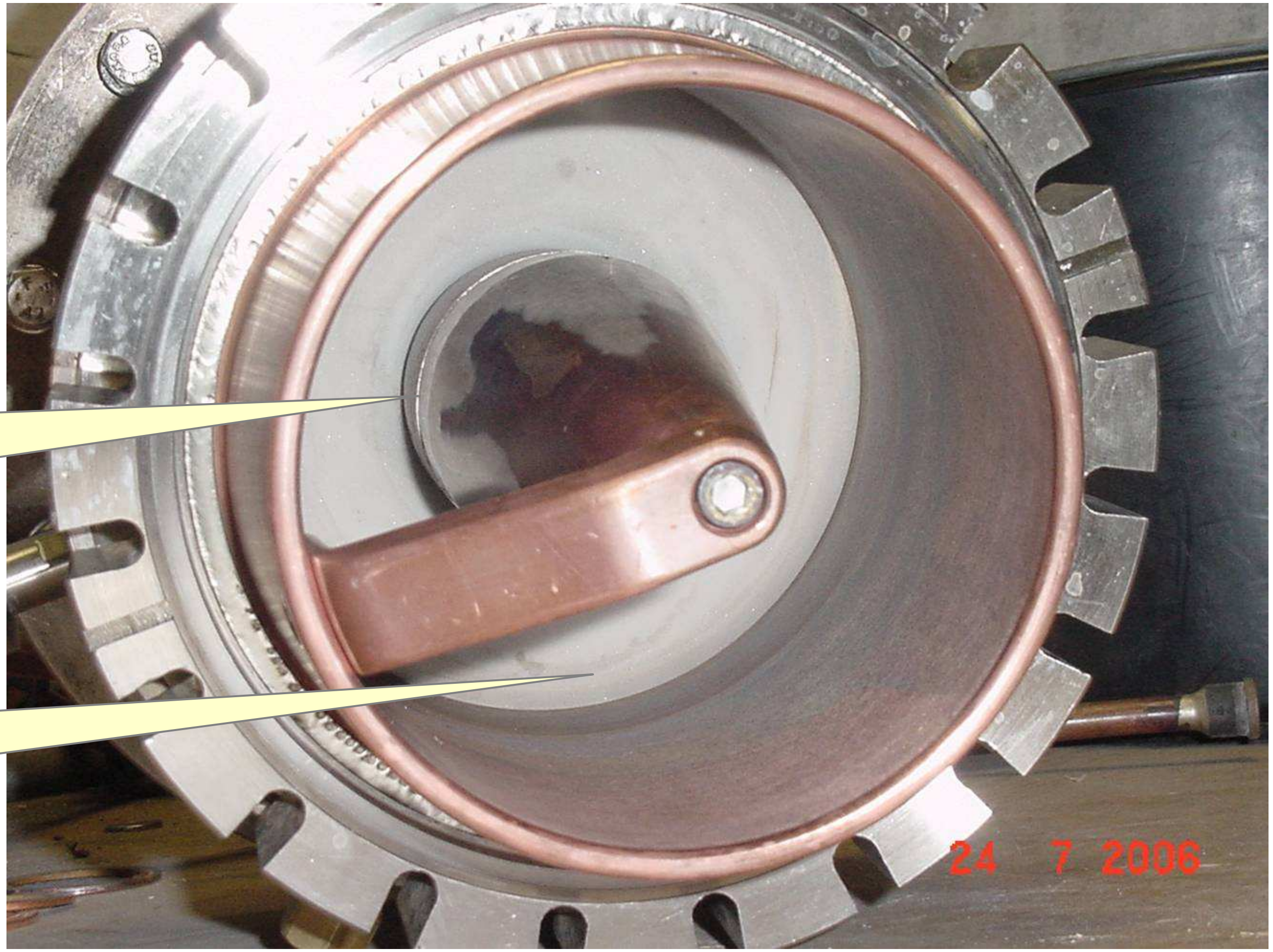
Previous Experience:

Just few couplers could be conditioned up to 150 kW or higher.

Most of them arced already at lower power levels.

The arcs caused copper erosion mainly on the centre conductor next to the vacuum window.

Copper deposition on the ceramic surface led to rf losses and overheating of the vacuum window.



A First Successful Measure

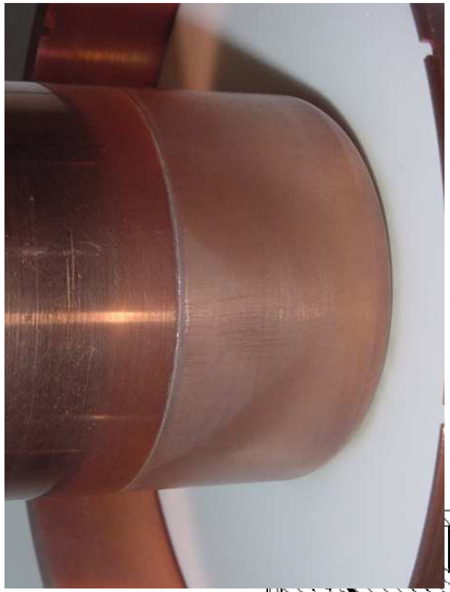
The couplers failed during conditioning or operating show **scars** due to copper erosion **mainly at a brazing joint** of the centre conductor.

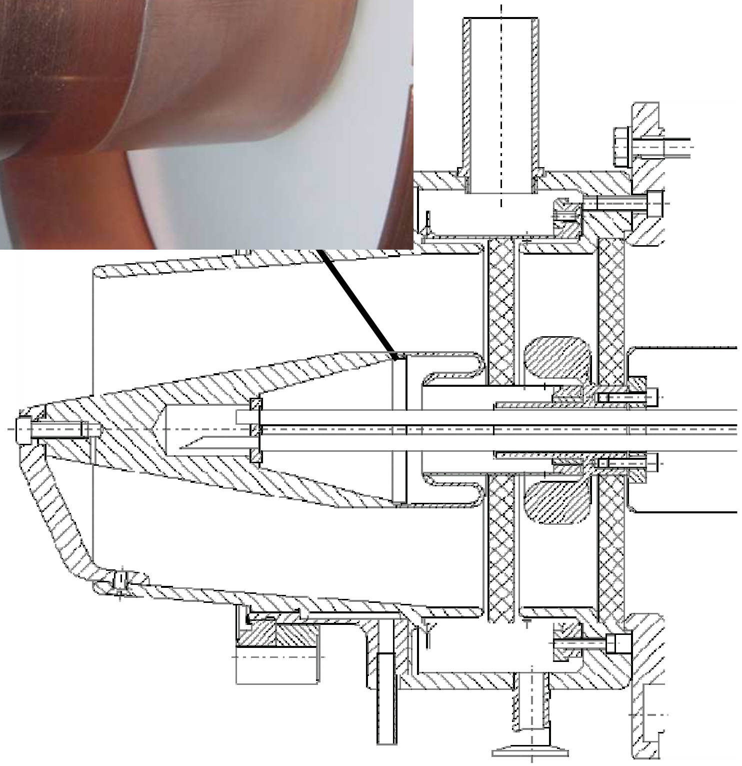
It was assumed that multipactoring is the cause (the used brazing solder has a high silver content).

The first idea was to cover the brazing joint region with a low SEY material.

Experiments with Aquadag® seemed to be promising. Two coated couplers reached 250kW without problems.

Aquadag® M is a colloidal dispersion of extremely fine, pure graphite in a water carrier that dries to form an adherent film on virtually all surfaces





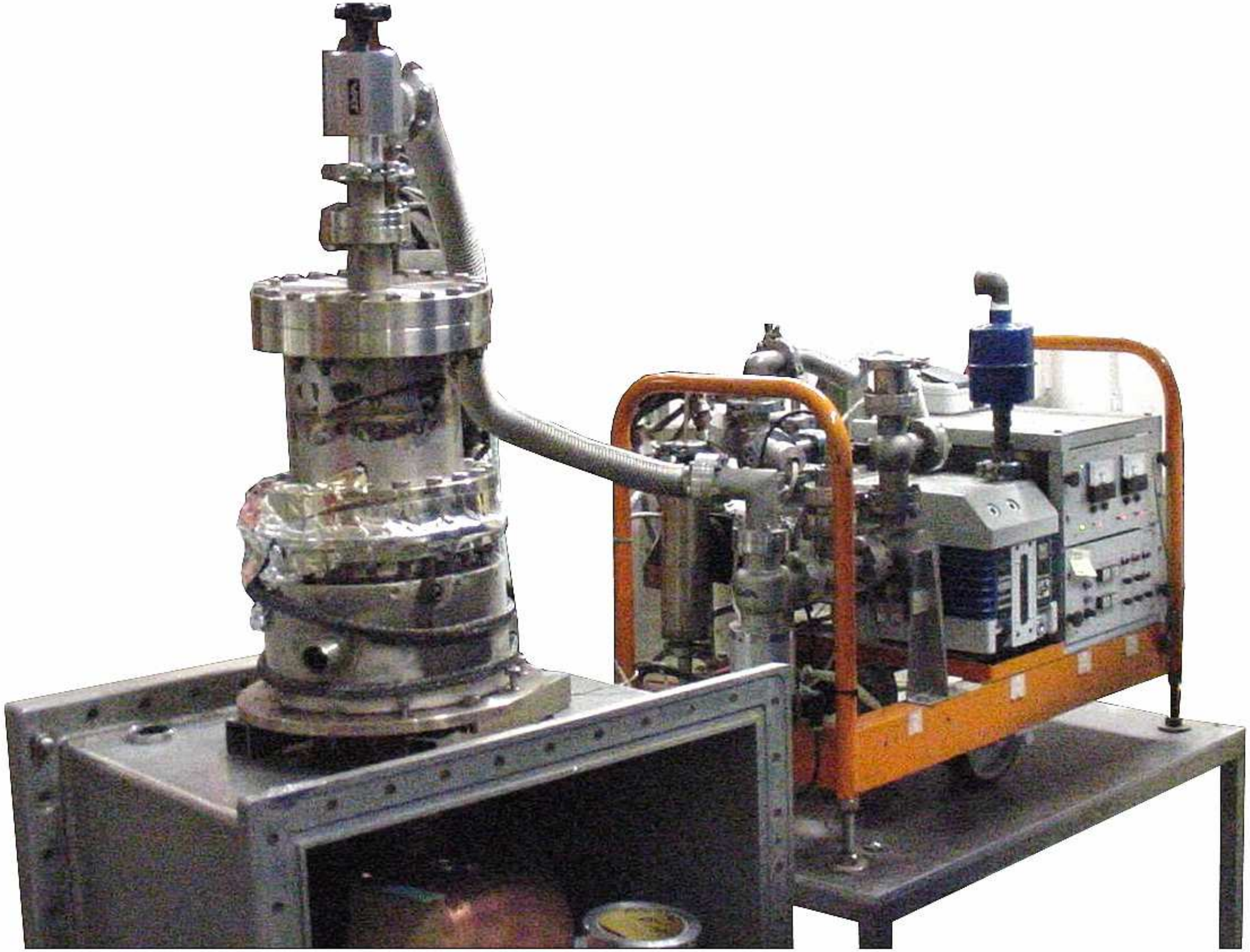
At the same time a couple of other measures showed success

Successful Improvements

1. Installation of an arc detector in order to switch of the rf power already when the arc occurs and not until the vacuum pressure exceeds the switch-off level.
2. Exhausting the coupler two days at 200℃ before installation and starting of the conditioning process.
3. Reducing of the rf power ramping speed from 60 kW/min to about 15 kW/min
4. Extension of the intermediate plateau from 2 min to 30 min.
5. FM of the Klystron rf (f_{mod}=400Hz, Δf=±100kHz)

A coupler, failed twice during previous conditioning processes, could be conditioned to 200 kW by this measures!

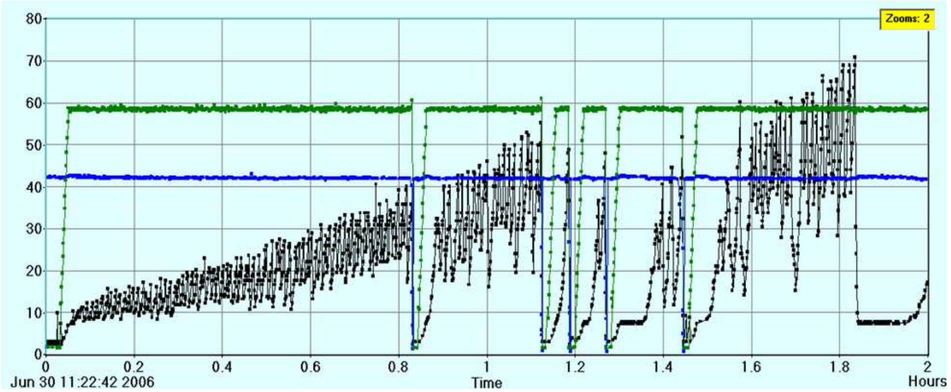
Exhausting Set Up

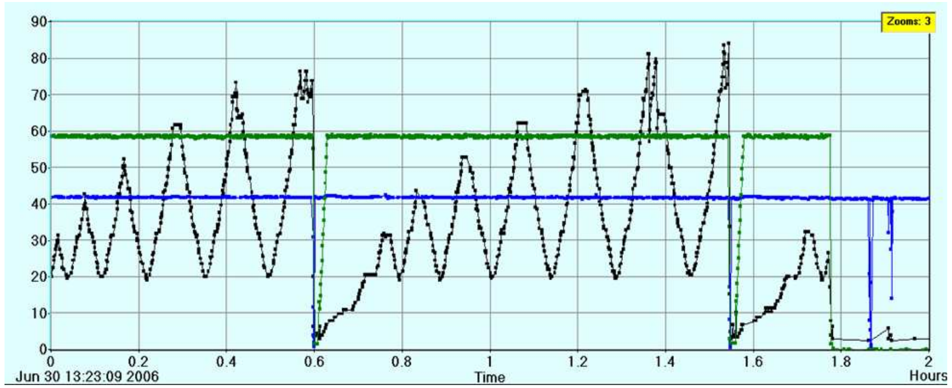


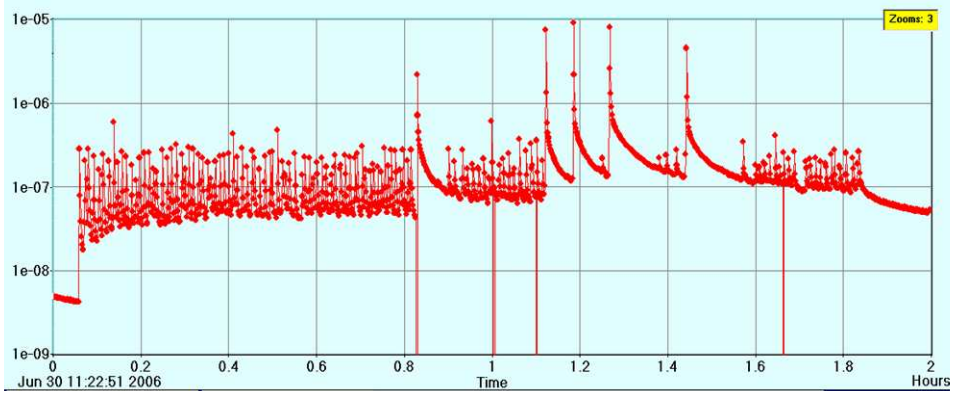
Effect of Reduced RF Power Ramp Speed

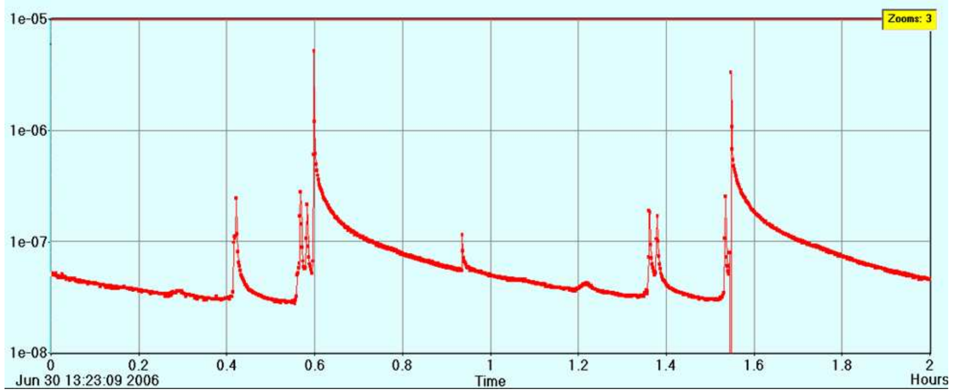
Heavy outgasing due to the high ramp speed (up to 60 kW/min)

Same coupler after the ramp speed was reduced to 15 kW/min







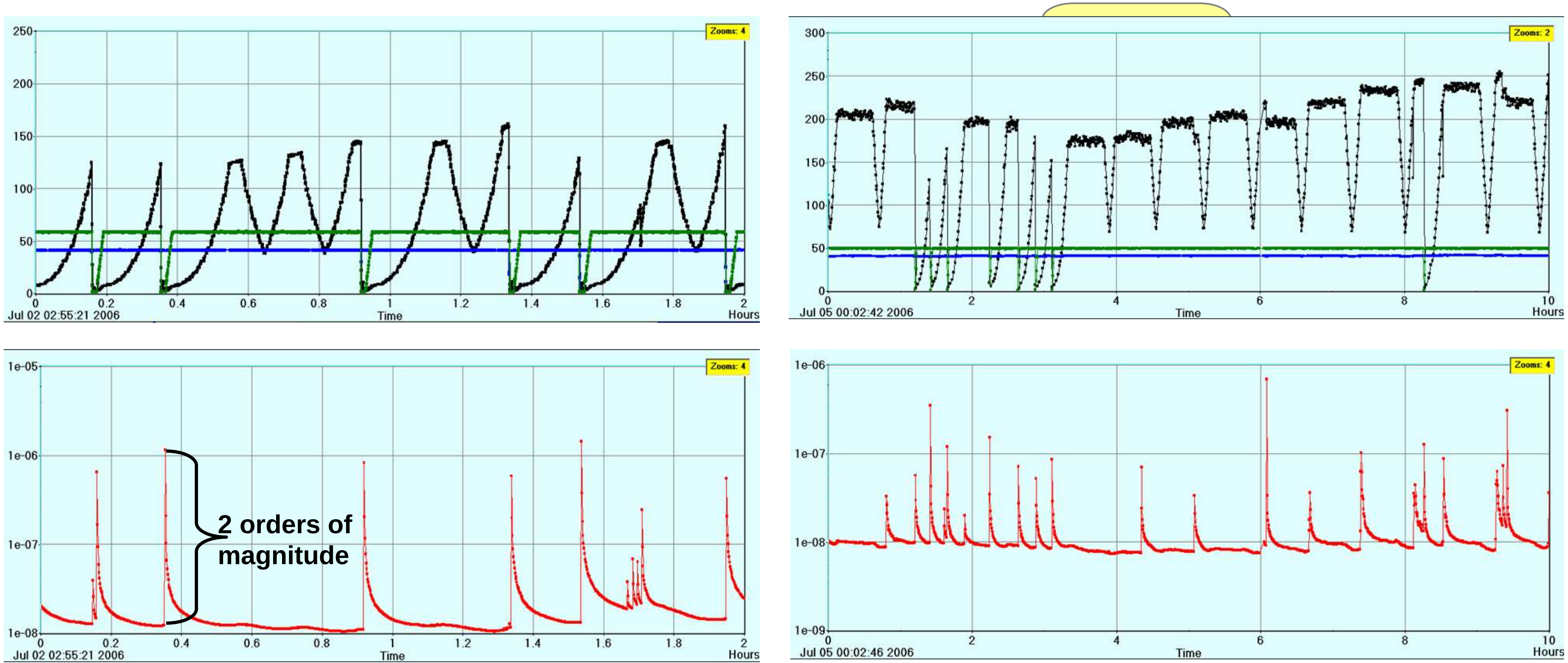


RF-Power [kW], Klystron-HV [kV], Klystron Drive Power [W], Cavity-Vacuum [mbar]

Intermediate Constant Power Plateau Extended

After 40h conditioning the progress stagnates due to strong sporadic outgasing

By extending the time of the Intermediate Plateau from about 2 to 30 Minutes the strong sporadic outgasing has been overcome



RF-Power [kW], **Klystron-HV [kV],** **Klystron Drive Power [W],** **Cavity-Vacuum [mbar]**

Breakthrough

One day in July ´06 I saw the exhausting vacuum chamber lying on the dirty floor.

Upcoming question:

Could it be that decades of unqualified dealing with UHV components has contaminated the vacuum surfaces of our couplers deeper than etching can remove?

For the answer the next couplers were sandblasted.

Sandblasting Experiments

- The vacuum surfaces of 4 couplers were sandblasted.
- Result: all reach >250 kW without any problem.
- New question:
  - Were problems really caused by deep contaminations?
  - Or was multipactoring the problem?
- Experiment:
  - Of one coupler only the centre conductor was sandblasted.
  - Of another coupler just the outer conductor was sandblasted.
- Expectation:
  - **Centre conductor sandblasted** should help if m.p is the cause of arcing. Because the brazed joint of the centre conductor was suspected to be a source of m.p..
  - **Outer conductor sandblasted** should help if contamination is the cause of arcing, because the surface of the outer conductor is > 2.3 times the surface of the inner conductor.

- Result:
  - **The coupler with centre conductor sandblasted reach >250 kW without any problem.**
  - **The coupler with outer conductor sandblasted failed.**

Our Today's State-Of-The-Art

Traditional versus New Invented Pre-Treatment and Conditioning Method

	Success by using the **traditional** pre-treatment and conditioning method	Success by using the **new invented** pre-treatment and conditioning method
Percentage of couplers which could be conditioned up to 250 kW	8/27 ≈ 30%	14/14 = 100%
Number of vacuum breakdowns during conditioning caused by coupler arcing	Max: 212 Ø: 60 Min: 3	Max: 34 Ø: 3 [1)] Min: 0
Duration of the conditioning processes	Max: 118h Ø: 46h Min: 16h	Max: 35h Ø: 24h Min: 5h [2)]

1) **One of 14 couplers arced 34, one 12, one 1 times, 11 couplers didn't arc at all!**

2) **The last 5 couplers are just ramped slowly from 0 to > 250kW without conditioning!**

Summary

- After the implementation of a couple of new measures the power capability of the old PETRA-type cavity couplers has been upgraded from <100kW to >250kW.
- Simultaneous the conditioning time has been reduced and the conditioning success has been improved.

Successful Measures:

1. Sandblasting of the vacuum surfaces in order to suppress multipactoring
2. ≈50h exhausting at 200…250℃ @ $p_{vac} \approx 10^{-6}$mbar directly before installation to the cavity.
3. Optimized conditioning process
   - lower power ramp speed
   - longer burn-in time at intermediate power levels,
   - FM of the rf.
4. Arc-Detector interlock for faster switch-off in case of coupler arcing

ANNEX

- Sandblasted Center Conductor
- Coupler Test Station with Arc-Detector
- Arc-Detector vs Vacuum-Interock
- Data PETRA-3 TDR

Sandblasted Center Conductor

Before Sandblasting

R_a = 0.624 µm
R_z = 3.82 µm

R_a = 0.380 µm
R_z = 3.00 µm

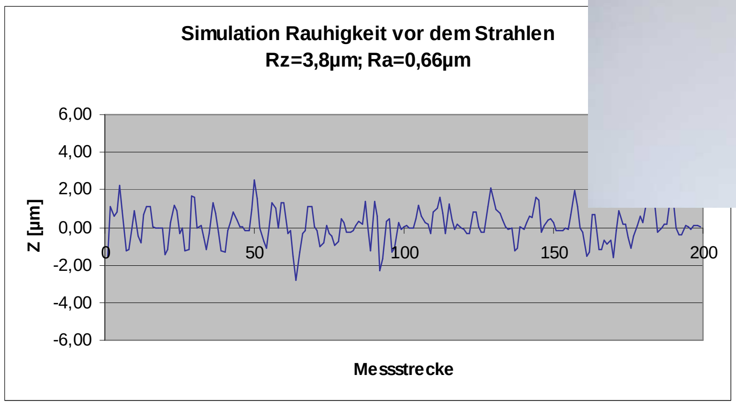
R_a = 0.338 µm
R_z = 2.05 µm

After Sandblasting

R_a = 1.651 µm
R_z = 9.46 µm

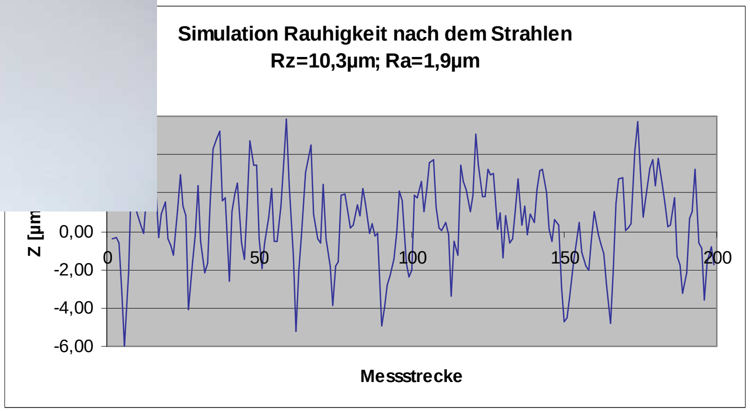
R_a = 2.164 µm
R_z = 11.9 µm

R_a = 1.994 µm
R_z = 11.6 µm



average surface roughness

R_z: Rautiefe, rouhgness depth



HELMHOLTZ | GEMEINSCHAFT

DESY

C.P. SYSTEM

C.P.- Poliermittel

Typ 100

Sandstrahlen ohne Sand

Technische Daten

Strahlmittel nach DIN 12111
Mischkörnung ________ 0,1 - 0,2 mm
Härte ________ 7 mohs
Schüttdichte ________ 1,6 kg/ m3
Kornform ________ Kugel
Mengeneinheit ___ 5 l/vol.- ca.10 kg
C.P.-Nr. ________ 265110

C.P.- Poliermittel 100

Ist ein Strahlmittel in Kugelform, die Glasperlen bestehen aus Kristallgllas, sind frei von toxischischen Bestandteilen entsprechen den tech. Regeln für gefährliche Arbeitsstoffe - TRgA 503 - und ist als nicht-silikogenes Strahlmittel zugelassen.

Einsatzgebiete

Zum Oberflächenverdichten (Polieren) von Aluminium, Edelstahl, Messing, Kupfer und sonstigen Buntmetallen. Im Behälterbau zum Nachbehandeln von Schweißnähten bei Edelstahlbehältern, oder im Kfz-Bereich zum Nachbehandeln von Zylinderköpfen, Ventildeckeln und vielem mehr. Es muß jedoch immer mit einem kantigen Strahlmittel zum Beispiel unserem C.P.-Strahlmittel 07 oder unserem C.P.-Feinstrahlmittel 03 unbedingt vorgestrahlt werden, denn eine Kugel als Strahlmittel kann nur Oberflächen verdichten und nicht richtig reinigen.

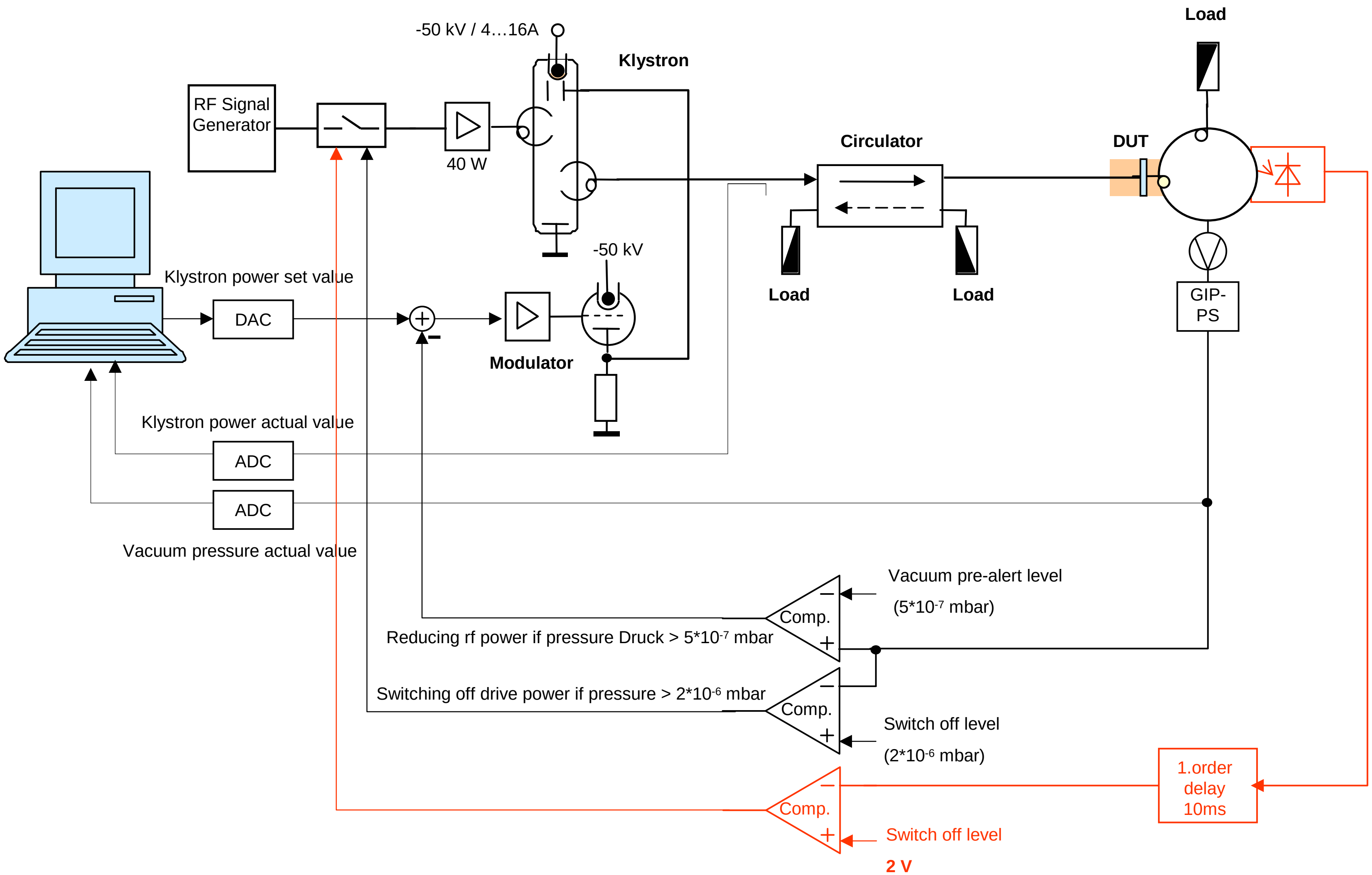
Falsches Strahlmittel ?

Ein falsches Strahlmittel hat außer einer unter Umständen erheblich verminderten Leistung weitere nachteilige Auswirkungen: ein Material mit zu geringer Härte führt zu längerer Strahlzeit und hohem Strahlmittelverbrauch; bei einer falschen Körnung läßt sich das Strahlmittel nicht gleichmäßig ansaugen oder führt zu Verstopfungen. Ein Material, bei dem die Feinteile nicht ausgesiebt sind, weist bei gleichem Volumen ein wesentlich höheres Gewicht auf, das bedeutet, daß beim Kauf über 50% Abfall mitbezahlt wird, der sich beim Strahlen leistungsmindernd auswirkt und eine Gesundheitsgefahr darstellt, die vermeidbar ist.

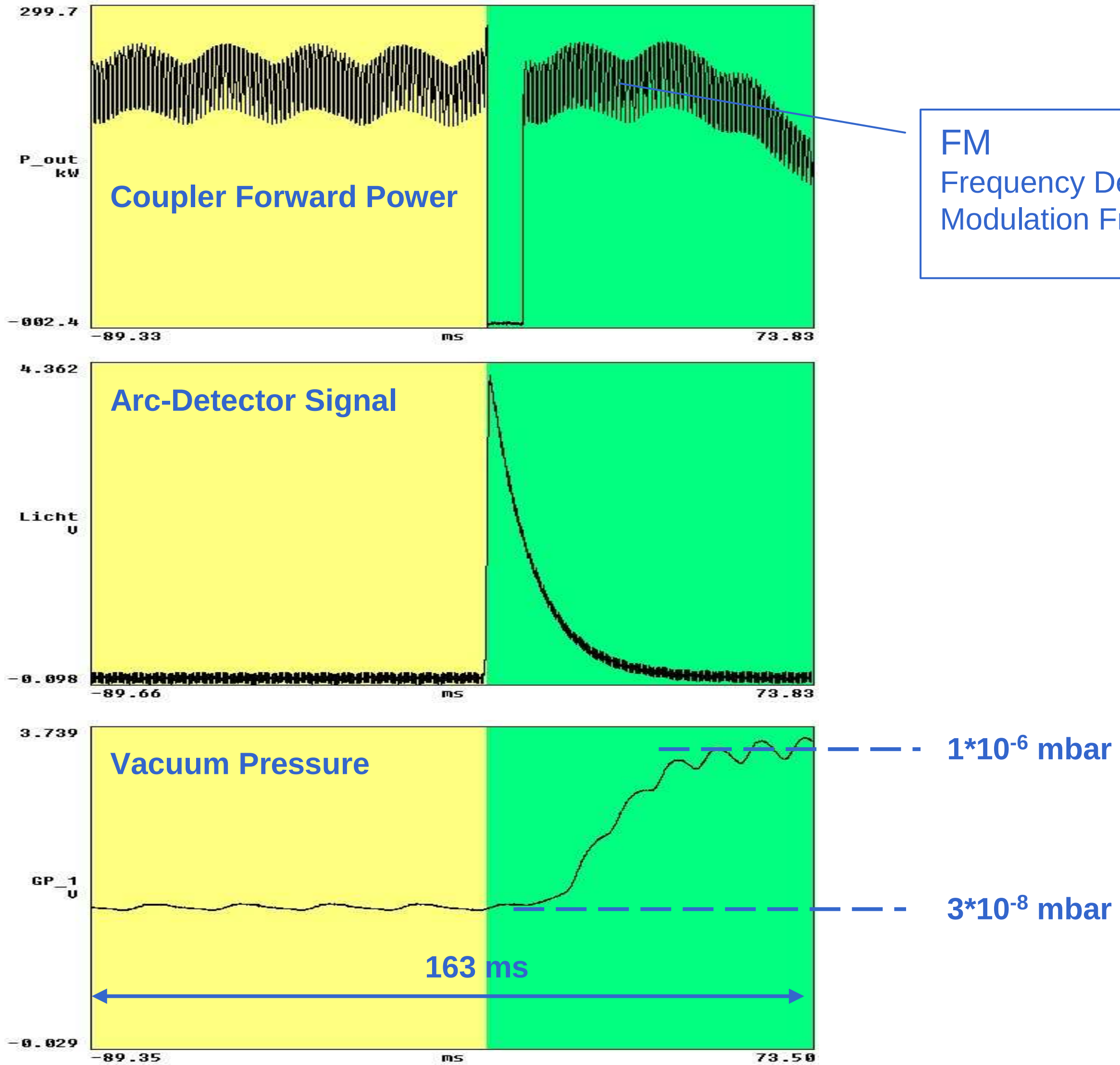
http://cepe.com

C.P. - SYSTEM Strahltechnik GmbH
Nordendstraße 86 - 88 Stadtteil W.
64546 Mörfelden - Walldorf Germany
Tel.06105/71006, FAX06105/75688

Coupler Test Station with Arc-Detector



Arc-Detector vs Vacuum-Interock



FM
Frequency Deviation: 100 kHz
Modulation Frequency: 400 Hz

PETRA-3 Data from TDR

Transmitter	Units	Nominal Data	Data for nominal Beam Operation @ 20MV, 100mA	Data for 1-Transmitter Operation @1440kW
No. of Transmitters	-	2	2	1
Number of Klystrons	-	4	4	2
Klystron Voltage	kV	75	60	73
Klystron Current	A	<18	<13	<17
RF Frequency	MHz	499.67	499.67	499.67
Klystron RF -Output Power	kW	800	398	720
Klystron Efficiency	%	>60	>50	>55

Cavities	Units	Nominal Data	Data for nominal Beam Operation @ 20MV, 100mA	Data for 1-Transmitter Operation @1440kW
No. of Cavities	-	12	12	12
Cavity-Type	-	7-cell, copper	7-cell, copper	7-cell, copper
Shunt-Impedance per Cavity	MW	23	23	23
Voltage per Cavity	MV	>2.5	1.67	1.67
Overvoltage Factor	-	-	2.6	2.6
Beam Current	mA	-	100	83
Synchronous Phase	degree	-	22.3	22.3
Cavity Detuning	degree		40.4	35.2
Cavity Detuning	kHz		21.3	17.7
Copper Loss per Cavity	kW	>150	60.3	60.3
Coupling Factor	-	-	2.0	2.0
Power per Coupler	kW	200	124	113
Power to Beam per Cavity	kW	-	63.2	52.5