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Title: SPARKING RATES MEASURED ON THE CRITS RFQ

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1. Automatic acquisition system.

During the test of the LEDA injector on the CRITS RFQ, an automatic data acquisition system has been implemented (fig.1). The purpose was to measure the sparking rate of this CW RFQ.
Sparks are detected in the blanking box by comparing the reflected power level to a preset threshold. In that case, the blanking box switches the low-level RF off for 70 µs, and this event is recorded by a pulse counter. The forward, reflected and cavity power levels are measured by RF power meters. The cavity residual vacuum is measured by a vacuum gauge. This diagnostic equipment is with the computer via a GPIB link.
The computer holds a Labview acquisition program that was launched at the beginning of every run. This program acquires the sparking counter every second and displays this information in a rolling window that holds the last four minutes of operation. Every minute, the computer reads the three RF powers and the vacuum pressure. Those information are stored with the total number of sparks during this minute, and the number of second during which at least one spark occurred. The time is also recorded.
The data are stored in an ASCII text file named *spk***.dat* (*** being a number automatically incremented by the program at each run) that can be read by any text editor. The list of the recorded files is displayed on table 1.

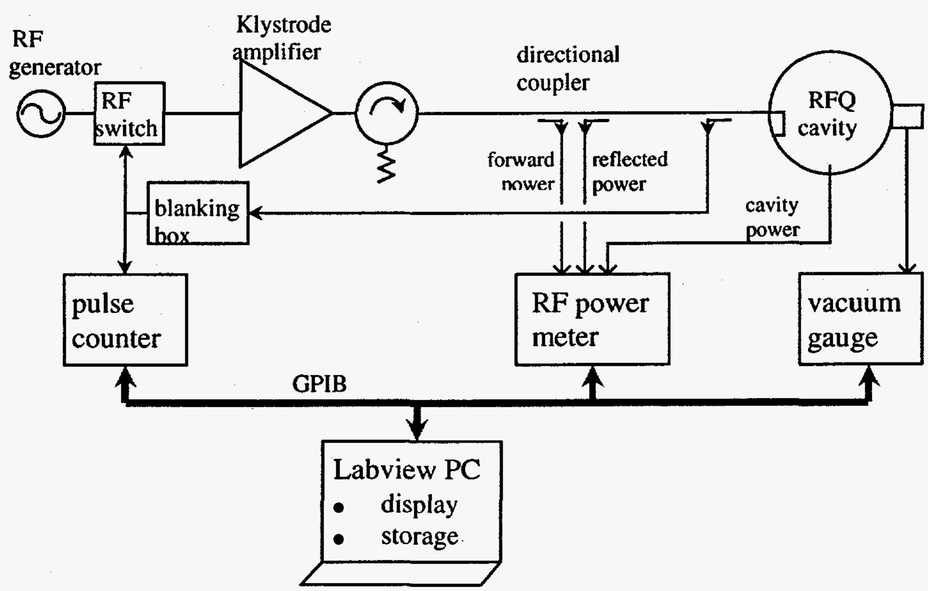

Fig 1. A Labview based automatic sparking rate acquisition system for the CRITS RFQ.

2. Examples.

The example displayed on figure 2 has been recorded on March 16, 1998. One can notice that the sparking rate gradually increased (between 11:30 and 12:00) while the RF power was raised for conditioning. The residual vacuum only slightly increased during that time. The reflected power is low, though not null, as the cavity is over-coupled without beam.
At 12:53, the power was dropped down to 120 kW, and no spark occurred during the following 11 minutes.
At 13:05, the beam was switched on. As a feedback circuit automatically compensates the beam loading, the cavity power remained constant. The forward power jumped from 137 to 185 kW and the reflected power almost vanished. The sparking rate increased significantly as the residual vacuum pressure increased approximately by a factor of ten.

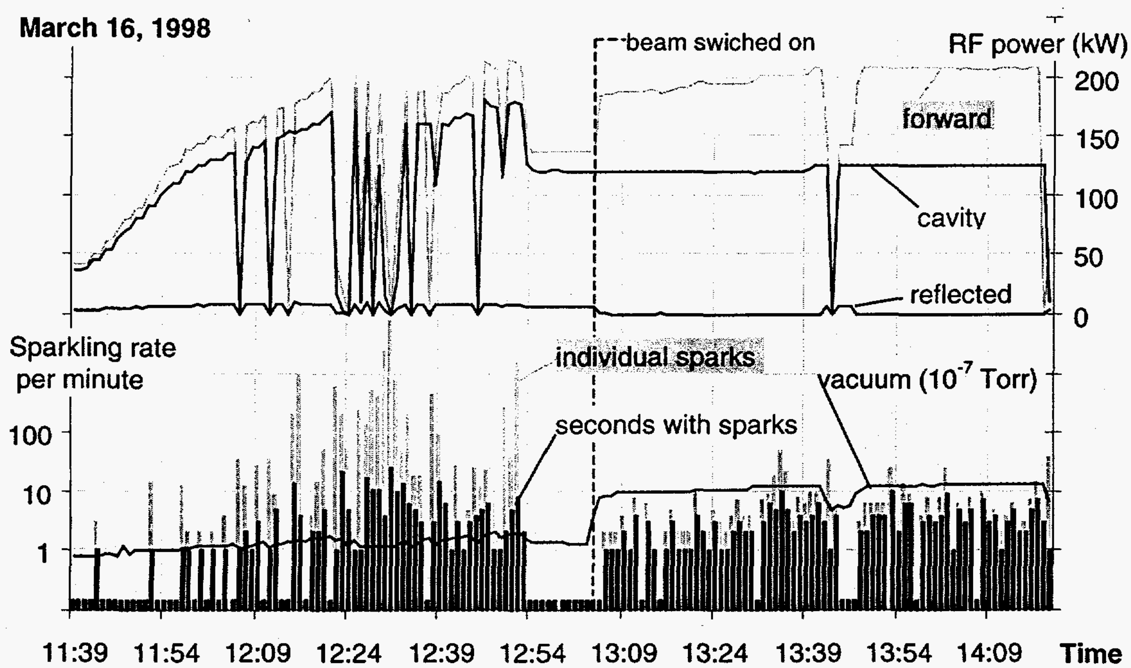

Fig.2. An example of automatically stored operating data.

The raw sparking rate is not always relevant information. Sometimes, bursts of sparks occur, and these bursts dramatically affect the average sparking rate. The average sparking rate is not really meaningful during these spark bursts since they can dominate the statistics presented by the average sparking rate. For that reason, we also stored the number of seconds during which at least one spark occurred. Doing this allows us to count these burst as only one event, and makes the statistics more reproducible. As an example, figure 3 is a record of the April 9 operation with an 80-mA beam. A burst of 708 sparks occurred in the middle of a continuous 61 minutes run. This single event changed the raw sparking rate from 5.1 to 16.7 per minute, but the rate of sparking seconds only changed from 3.00 to 3.06.

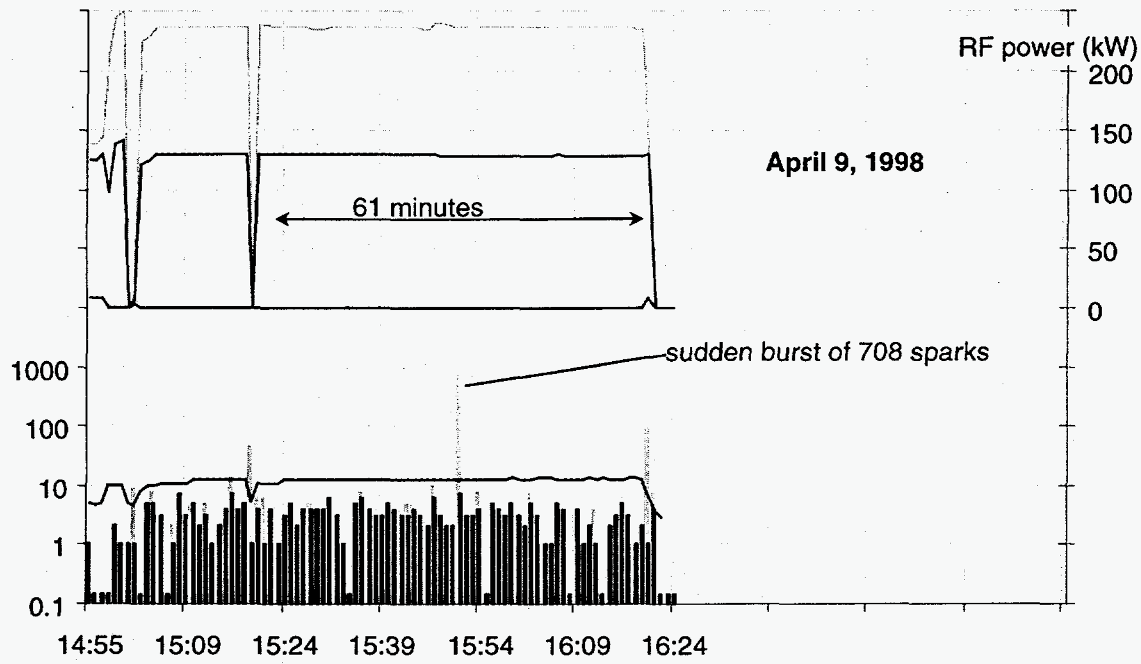

Fig. 3. Burst of sparks biasing the raw sparking rate statistic.

3. Sparking rate analysis.

3.1. Operations without beam.

The 34 long runs (between 22 and 163 minutes long) of continuous operation without beam that have been collected are printed on table 2. Some of them yielded no sparks at all. Figure 4 plots the number of sparking seconds in a log scale. One spark has been added arbitrarily to each data point in order to be able to plot the zero-spark points. This induces a slight bias to the other data, but takes into account the fact that rates are more accurate if acquired over a long run.

At the design field (1.75 Kilp.), the sparking rate is typically 0.5 per min, i.e. the average time between two bunches of sparks is two minutes. The slope suggests that a 0.22 Kilp decrement in the electric field lowers the sparking tendency by an order of magnitude.

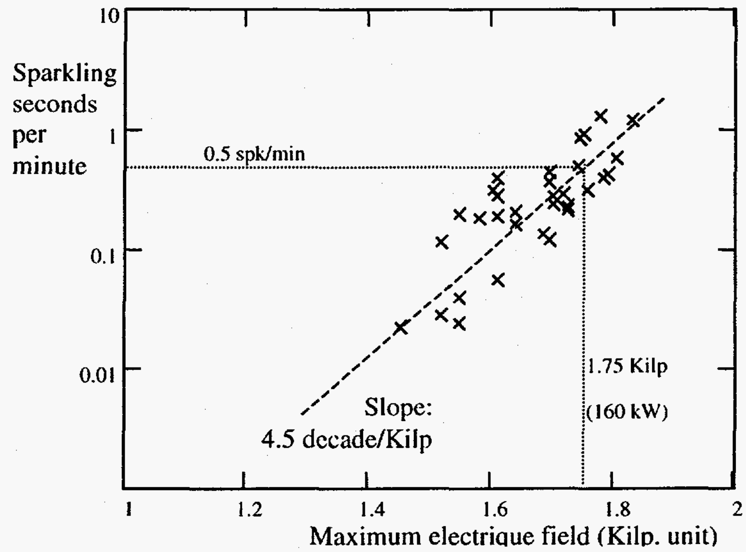

Fig. 4. Sparking rate measured during no-beam operations.

3.2 Operations with beam.

Beam operations have also been considered. The long runs with continuous beam operation are printed on table 3: 24 runs (between 24 and 161 minutes long) for a beam current between 20 and 80 mA. Because of a peak RF power limitation, the RFQ was run at about 10 % below the design cavity field (1.75 Kilpatrick, 77.4 kV intervane voltage, 159 kW measured in the RFQ). The beam current value listed in the table is deduced from RF power data and may differ slightly from the direct current measurements.
Figure 5 shows that the range of beam current variations was too narrow to induce a significant variation of the sparking rate. In the range of current tested, the number of sparking second is about 3 per minute, which is about 30 times more than without beam.
Figure 6 shows that the sparking rate does not follow the dependency rule versus electric field that has been established without beam. However, this information has to be taken with care, because when the field differs from the design value, the synchronism between beam velocity and vane modulation is no longer satisfied.

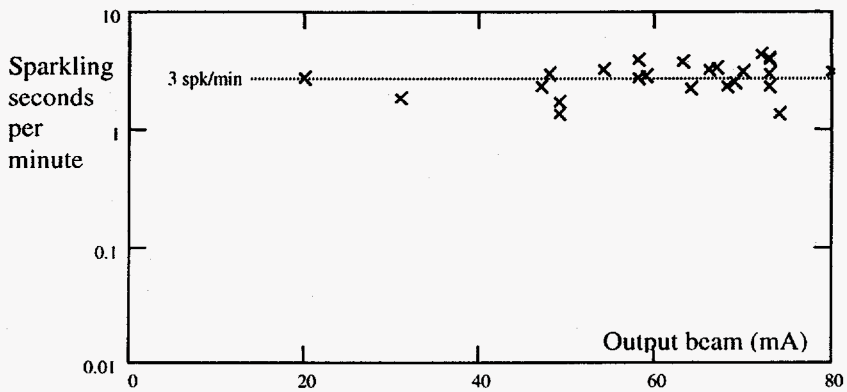

Fig. 5. Sparking rate versus beam current

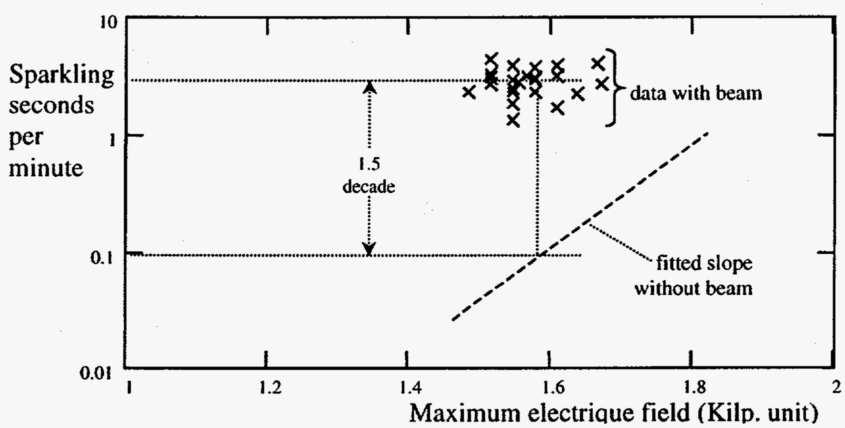

Fig. 6. Sparking rate comparison: with-beam versus no-beam

4. Conclusion

The RF level has some influences on vacuum, but there is no evidence of any reciprocal effect.

The raw sparking rate is very difficult to interpret, since bursts of sparks bias the statistics. A more convenient and useful interpretation is the number of sparking seconds.

At the nominal field level (1.75 Kilp), the sparking-second rate is 0.5 per minute without beam. It strongly depends on the field, with a logarithmic law: 4.5 decade/Kilp.

With beam, the sparking rate jumps to 3.0 per minute. As far as tested, it depends neither on the beam current (20 to 80 mA) nor on the field (1.5 to 1.7 Kilp tested).

With sparking rates as measured here, one could not hope to build an RFQ that would be free of sparks over a several months continuous operation. Such a requirement, based on an extrapolation of the curves presented here, would lead to a maximal electric field much lower than the Kilpatrick value, an unreasonable requirement for a functional RFQ.

A conclusion is that a sparkless RFQ is hopeless, even with a very carefully conditioned cavity. It will probably be necessary to deal with a few sparks per day, and the linac must be able to restart automatically after a short beam interruption.

Table 1.

List of all the automatically recorded runs of the CRITS RFQ during the LEDA injector experiments (sep 97- apr 98)

file	kbytes	date
109	13	12 nov
115	3	13 nov
116	6	14 nov
125	8	7 jan
126	18	9 jan
127	14	9 jan
142	12	14 jan
143	10	20 jan
144	3	21 jan
145	19	21 jan
146	4	22 jan
149	4	23 jan
152	5	27 jan
153	9	27 jan
156	10	27 jan
158	4	29 jan
159	16	30 jan
162	13	4 feb
163	20	5 feb
164	4	9 feb
165	1	11 feb
166	1	12 feb
167	1	12 feb
168	24	13 feb
169	23	17 feb
170	13	18 feb
171	7	19 feb
172	2	19 feb
173	1	23 feb
174	1	13 feb
175	2	24 feb
176	3	24 feb
177	7	24 feb
178	27	25 feb
179	11	26 feb
180	38	4 mar
181	34	5 mar
182	32	6 mar
183	1	8 mar
184	4	9 mar
185	7	9 mar
186	9	9 mar
187	34	10 mar
188	25	11 mar
189	24	12 mar
190	29	13 mar
191	5	14 mar
192	14	16 mar
193	22	17 mar
194	8	18 mar
195	13	18 mar
196	10	23 mar
197	12	24 mar
198	3	26 mar
199	16	27 mar
200	21	30 mar
201	1	30 mar
202	12	30 mar
203	18	31 mar
205	10	1 avr
206	3	3 avr
207	7	3 avr
208	6	8 avr
209	7	9 avr
210	12	9 avr
211	5	9 avr

Table 2.
List of the long continuous runs of the CRITS RFQ **without beam** recorded during the LEDA injector experiments (sep 97- apr 98)

file	date m.day	time hr.mn	durat. min	RFQ kW	E-pk Kilp	beam mA	spk total	sp-sec total	spk /min	sp-sec /min	
176	2.24	10.3	25	125	1.55	0	0	0	0.00	0.000	
178	2.25	15.3	58	148	1.69	0	12	7	0.21	0.201	
180	3.04	9.3	68	120	1.52	0	31	7	0.46	0.172	
180	3.04	10.4	43	140	1.64	0	65	8	1.51	0.310	
180	3.04	11.4	30	140	1.64	0	34	4	1.13	0.222	
180	3.04	12.1	71	151	1.71	0	134	19	1.89	0.446	
180	3.04	13.3	163	151	1.71	0	300	38	1.84	0.389	
181	3.05	7.3	70	152	1.71	0	103	17	1.47	0.405	
181	3.05	10.3	30	125	1.55	0	42	5	1.40	0.278	
181	3.05	12.2	33	135	1.61	0	41	12	1.24	0.606	
181	3.05	12.5	27	150	1.70	0	74	11	2.74	0.679	
181	3.05	16.1	60	150	1.70	0	95	21	1.58	0.583	
182	3.06	8.1	38	166	1.79	0	90	14	2.37	0.614	
182	3.06	9.4	39	167	1.79	0	124	16	3.18	0.684	
182	3.06	14.1	48	154	1.72	0	55	13	1.15	0.451	
182	3.06	15.4	38	161	1.76	0	42	11	1.11	0.482	
182	3.06	16.2	29	170	1.81	0	352	16	12.14	0.920	
184	3.08	17.1	33	170	1.81	0	162	18	4.91	0.909	
187	3.1	8.1	45	110	1.46	0	0	0	0.00	0.000	
187	3.1	12.4	33	150	1.70	0	13	3	0.39	0.152	
187	3.1	14.1	89	155	1.73	0	406	18	4.56	0.337	
187	3.1	16.1	33	165	1.78	0	1063	43	32.21	2.172	
187	3.1	16.4	26	175	1.84	0	130	30	5.00	1.923	
188	3.11	5.5	36	120	1.52	0	0	0	0.00	0.000	
188	3.11	8.1	42	125	1.55	0	0	0	0.00	0.000	
188	3.11	9.3	38	130	1.58	0	100	6	2.63	0.263	
190	3.13	10.2	35	135	1.61	0	2	1	0.06	0.048	
190	3.13	12.1	48	155	1.73	0	144	10	3.00	0.347	
197	3.24	10.3	34	160	1.76	0	424	31	12.47	1.520	unstable level
199	3.26	13.5	44	158	1.74	0	258	21	5.86	0.795	
200	3.3	7.5	22	159	1.75	0	407	18	18.50	1.364	
200	3.3	17.4	49	135	1.61	0	53	13	1.08	0.442	
200	3.3	18.4	42	135	1.61	0	30	7	0.71	0.278	
208	4.08	15.2	35	134	1.61	0	108	10	3.09	0.476	

Table 3.
List of the long continuous runs of the CRITS RFQ **with beam** recorded during the LEDA injector experiments (sep 97- apr 98).

file	date m.day	time hr.mn	durat. min	RFQ kW	E-pk Kilp	beam mA	spk total	sp-sec total	spk /min	sp-sec /min	
127	1.09	14.3	32	146	1.68	20	1441	85	45.0	4.43	
142	1.14	10.5	36	125	1.55	31	189	66	5.3	3.06	
142	1.14	12.2	69	125	1.55	47	253	161	3.7	3.89	
142	1.14	13.5	24	125	1.55	49	86	32	3.6	2.22	
149	1.23	16.5	30	140	1.64	64	124	66	4.1	3.67	
162	2.04	15.4	75	125	1.55	74	176	102	2.3	2.27	
169	2.17	14.2	22	125	1.55	69	84	54	3.8	4.09	
169	2.17	15.1	23	130	1.58	73	106	67	4.6	4.86	
181	3.05	9.5	52	125	1.55	48	739	156	14.2	5.00	
181	3.05	11.2	54	135	1.61	54	828	171	15.3	5.28	
181	3.05	14.1	48	135	1.61	49	239	82	5.0	2.85	
188	3.11	11.3	36	120	1.52	72	491	157	13.6	7.27	
189	3.12	12.5	45	120	1.52	67	489	147	10.9	5.44	
190	3.13	14.1	60	120	1.52	58	514	162	8.6	4.50	
190	3.13	15.3	41	126	1.56	59	438	116	10.7	4.72	
192	3.16	13.5	30	125	1.55	58	203	116	6.8	6.44	
192	3.16	14.3	24	125	1.55	58	160	91	6.7	6.32	
193	3.17	12.5	24	115	1.49	68	115	55	4.8	3.82	
193	3.17	13.4	62	120	1.52	70	462	187	7.5	5.03	
199	3.26	11.1	37	128	1.57	66	280	116	7.6	5.23	noise on current
199	3.26	12.1	52	145	1.67	73	1010	209	19.4	6.70	varying level
199	3.26	14.4	26	130	1.58	73	164	61	6.3	3.91	current up to 90
200	3.3	11.1	161	130	1.58	63	1929	597	12.0	6.18	unstable current:42-84 mA
202	3.3	15.5	65	135	1.61	73	896	257	13.8	6.59	
211	4.09	15.3	61	130	1.58	80	1024	187	16.8	5.11	