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STATUS OF THE CERN-KARLSRUHE SUPERCONDUCTING RF PARTICLE SEPARATOR

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Abstract

The present status of the rf separator is given. Measurements of single cavity sections and of two joined sections are reported. The problem of storing heat treated sections until final assembly has been investigated. Flooding a cavity at room temperature with nitrogen deteriorates its performance, after the cavity was once excited to a peak electric field of 30 MV/m, corresponding to a peak magnetic field of 850 G and a deflecting field of 5.5 MV/m. This effect is assumed to be due to a sensibilization of the surface oxides by field emission electrons. The effect is not observed after a electric field of up to 15 MV/m and it also does not appear when the cavity is flooded with argon.

I. Introduction

The general layout of the superconducting rf particle separator has been reported in recent conferences[1,2]. Measurements on single 60 cm long sections of the two three meter deflecting cavities showed a satisfactory performance with Q-values and deflecting fields well above the design values[2]. In ref.[3] a method for localizing bad spots on the cavity surface was developed. The next step was the combination of two sections to form a longer deflecting cavity. In this paper we will show our experiences during this step. Unexpected difficulties initiated some new experiments concerning the problems of rf joints and of gas exposure of the niobium cavities the results of which we summarize below.

II. Measurement of two combined sections

1. For the first measurement of a deflecting cavity of 1.20 m length we used two sections, D1 and D5 which had shown good results in earlier tests[2]. D1 and D5 are two end sections with a beam tube (D), a tuner cell (C) and a input coupling cell (B) each (Fig. 1). They were connected with a niobium rf joint (A) and an indium

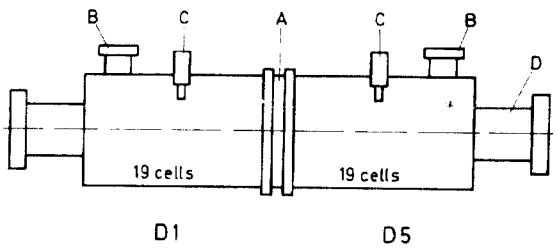

Fig. 1: 1.20 m long deflecting cavity

vacuum gasket described in [2] and measured horizontally in a 4 m-prototype cryostat. Prior to the measurement each section was electropolished 10 µ, anodized, oxypolished, rinsed with alcohol and heat treated at 1850°C for 2 h in a vacuum of better than 10^{-8} Torr ($1.3 \cdot 10^{-11}$ bar). As in our UHV furnace it is only possible to treat one section at a time the first section had to wait for final assembly until the second was heat treated. Therefore D1 was stored for 3 days in a 4 m long clean glove box which was flooded with dust free air. After this time D5 was brought into the glove box and the whole cavity was assembled within one hour. The results of this test are shown in Fig.2

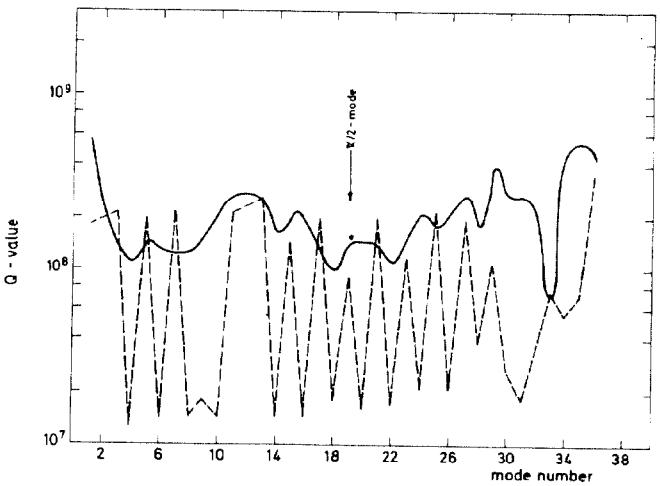

Fig.2: Q-value as function of the mode in first experiment on D1+D5; dashed line: before, solid line: after tightening the joint

where the measured Q-values at 1.8 K are plotted as function of the mode. The Q-values were generally low, the best values were about $3 \cdot 10^8$. This mode dependence is due to a poor joint. We then warmed the cavity up and retightened the joint. The Q-values measured afterwards are also shown in Fig.1. Some values were greatly improved, and the characteristic up-down pattern was less pronounced, showing that the joint had improved. At the time of this experiment we did not analyze the remaining pattern with a maximum at modes 10 and 29 and a minimum from 17 to 20. We assumed from the low mean value of the Q's that one half of the cavity had a poor surface due to the storing of one cavity section under air. As a consequence of the low Q-value the rf field could only be increased to 14 mT until thermal breakdown occurred. In order to improve this result we started two investigations which are summarized in chapter III and IV: At first we had to find out how storing the cavities under different gases affects their performance, and second we wanted to develop a more reliable joint. As these investigations were finished we started the second experiment on D1 and D5 which we will describe next.

2. Prior to the second run both sections were treated as in the first one. When D1 was removed from the furnace it was closed in the glove box within 45 minutes and pumped to $5 \cdot 10^{-7}$ Torr ($6.7 \cdot 10^{-10}$ bar). After the heat treatment of D5, D1 was let down to normal pressure with clean (99.995%), dry and filtered nitrogen and connected with D5 in the glove box. The total assembling time was 1 h. The joint ring used had dimensions according to the experien-

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ces shown in chapter IV. In Fig.3 the measured

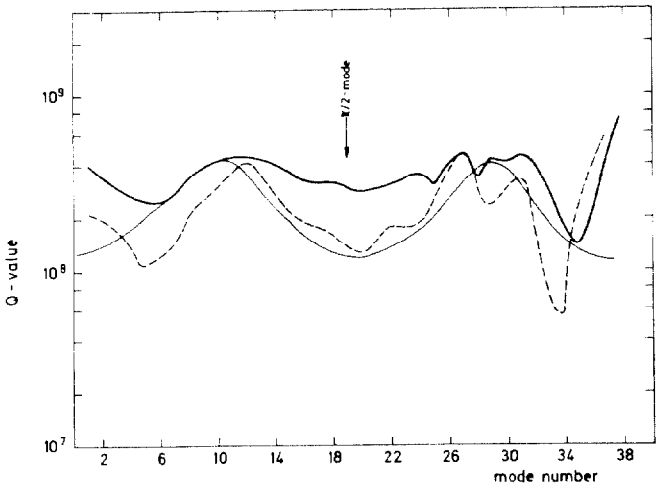

Fig.3: Q-value as function of the mode in second experiment on D1+D5 (0^{o}-modes) heavy solid line: before, dashed line: after multipactoring; light line: theoretical mode distribution assuming a bad spot in one of the coupling cells.

Q-values at 1.8 K are plotted as function of the mode. The pattern is similar to the one observed in Fig.2 after tightening the joint and was even more pronounced after a few minutes of multipactoring. The up-down dependence of the first experiment had disappeared showing that the joint was no longer dominating the surface losses. The analysis of this mode dependence showed a bad spot in one of the input coupling cells. Assuming the bad spot to be normal conducting we could calculate that its size might be of the order of a few mm^2.
We also measured the Q-values of the modes perpendicular to the operating mode (90^{o}-modes). The mode dependence (Fig.4) of these modes shows a different pattern: First, the Q-values are above our design value in several modes including the $\pi/2$-mode, showing that the surface is generally good; second, at these Q-values the influence of the joint can be seen. Since

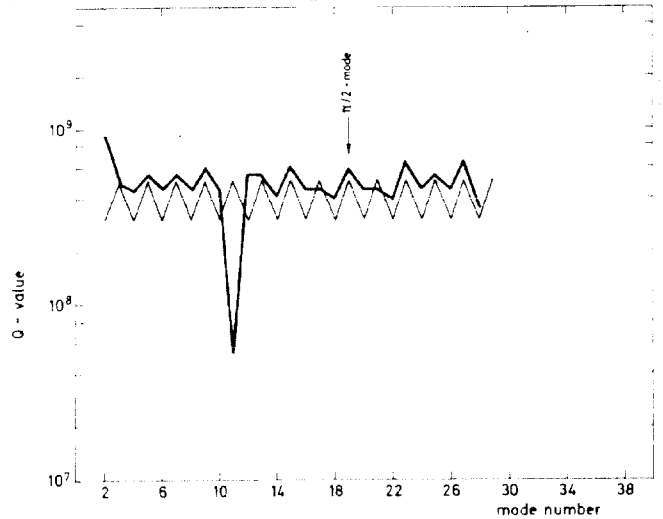

Fig.4: Q-value as function of mode for the perpendicular modes (90^{o}-modes) heavy line: measured; light line: theoretical, assuming a bad joint. (The low value at mode 11 is not understood.

the pattern of Fig.2 had disappeared we concluded that the bad spot in the coupling cell had to be situated under 0^{o} or 180^{o}, where the 90^{o}-modes have zero field. In the (90^{o}) $14\pi/38$-mode we were able to measure a breakdown field of approximately 29 mT. This shows also that the overall cavity surface is not too bad. Warming up the cavity to room temperature, tightening the bolts at the joint, heating the coupling cells by a fan to about 200^{o}C and an additional surface treatment procedure did not change the results. A careful inspection of the cavity after the experiment did not show any convincing candidate for the "dirt", although a little black spot in the coupling cell was observed.

III.Exposing of cavities to nitrogen and argon

We have reported earlier measurements[4], where a cavity had shown no sensitivity against gas exposure, but the results mentioned above made a more thorough investigation necessary. A.Brandelik et al.[5] reported that a vacuum failure with exposing a cold cavity to normal air could be cured simply by warming the cavity up. P.B.Wilson et al.[6] made gas exposure tests at 10 GHz with the aim of a better understanding of the cavity behavior; they found a degrading effect of carbon compounds (CO_2,CH_4). The purpose of our investigation was mainly directed towards the more practical questions outlined above.

For the tests we used two almost identical 4 cell iris loaded deflecting cavities, S IV and S VIII. Both were used for many previous experiments reported elsewhere[4,7,8]. To restore well defined initial experimental conditions we gave the cavities a so called "standard treatment" consisting of 10μ electropolishing, anodizing and a heat treatment of 2 hours at 1850^{o}C.

In order to make sure, that the "standard treatment" gave always reproducibly the same results, we measured the cavities each time right after the treatment. After the initial measurement, we warmed the cavity up to room temperature and let it down to athmospheric pressure with the gas under investigation. We used nitrogen and argon with a purity of 99.995% and 99.999%, respectively. As an additional precaution we used a ceramic filter to prevent contamination with dust particles and a liquid nitrogen baffle to freeze out water and carbohydrates. A summary of all cavity measurements is shown in Table I. Comparing the results on S IV, (tests 1 through 3d) with those on S VIII, (tests 4 through 6a) one notices that each cavity gives reproducible results, but there appears a substantial difference between both cavities: S IV gives only 48 mT, but is not affected by exposure to air, nitrogen, or argon for up to 6 days. S VIII on the contrary, which yields reproducibly initial peak fields of 74-85 mT gives a sharp Q-drop below the design value after each gas exposure. To explain this difference we assumed that the behavior of S VIII is due to the very high field achieved in the initial test; we therefore measured in test 7 only the low field Q and allowed in test 7a only fields of the same order achieved in S IV. Test 7b finally showed that no deterioration occurred by the nitrogen exposure. This result agrees with observations by Kneisel et al.[9] and Lyneis et al.[10]. They explain it by radiation damage. Field emission electrons which are

Table I: Summary of results (ep: electropolished, a: anodized)

No.	Resonator	Q(H=0) $\cdot 10^9$	Q(H=H_p) $\cdot 10^9$	H_p (mT)	Treatment (all gas exposures at room temperature)	Remarks
1	S IV	2.9	1.4	47.0	30 μ ep, a, 30h 1850°C	Tests 1 through 2a reported previously[4]
1a	S IV	1.75	1.4	47.5	5 cooling cycles under vacuum	
1b	S IV	1.53	1.38	48.5	slowly let down with cleaned air within 24h	
1c	S IV	?	0.8	51.0	quick let down with air, 24h air	
2	S IV	7.4	4.5	49.5	a, 20h 1850°C	
2a	S IV	?	2.2	43.5	let down with N_2	
3	S IV	1.6	1.4	48.0	10 μ ep, a, 2h 1850°C	
3a	S IV	1.6	1.0	48.0	let down with argon, 15 min	
3b	S IV	1.3	0.89	57.0	let down with nitrogen, 15 min	60 h multipactoring
3d	S IV	1.25	1.1	44.0	let down with nitrogen, 6 days	23 h multipactoring
4	S VIII	3.6	2.6	74.0	10 μ ep, a, 2h 1850°C	
4a	S VIII	0.49	0.36	54.0	let down with air 24 h	
5	S VIII	4.6	2.4	85.0	15 μ ep, a, 2h 1850°C	
5a	S VIII	1.5(0.22)	0.15	42.0	let down with nitrogen 15 min	Q = 0.22·10^9 after mp.
5b	S VIII	0.22	-	-	2 weeks under vacuum at r.temp.	
6	S VIII	2.75	1.8	84.0	10 μ ep, a, 2h 1850°C	
6a	S VIII	3.1(0.04)	0.73	13.0	let down with nitrogen 15 min	Q=.04·10^9 after multip.
7	S VIII	2.1	-	-	10 μ ep, a, 2h 1850°C	only low field Q meas.
7a	S VIII	1.83	1.46	43.7	let down with nitrogen 15 min	only up to 437 G meas.
7b	S VIII	1.6	1.0	69.0	let down with nitrogen 15 min	27h multipacting
8	S VIII	1.1	0.72	58.0	10 μ ep, a, 2h 1850°C, assembled in glove box: see text	
9	S VIII	1.5	0.79	74.0	as in test 8	
9a	S VIII	1.5	0.64	76.0	let down with argon 1h	21h multipacting

observed in our experiment by rapidly increasing doses of γ-rays with increasing fields are able to change the surface in such a way, that subsequent exposure to nitrogen deteriorates the surface. At 500 G, or electric fields of 18 MV/m there are less electrons, and they do not gain sufficient energy for this radiation damage. Whether this deterioration of the surface is due to the nitrogen or to the impurities present in any gas has to be investigated more thoroughly in the future. We made, however, one experiment which indicates that argon seems to be less dangerous than nitrogen. In test 9a S VIII was flooded at room temperature with argon for one hour, and no deterioration occurred. Our result is not in contradiction to the papers by K.Schnitzke et al.[11] who find no deterioration in X-band cavities where electron loading is less severe than in S-band.

We then simulated the assembling of several sections of the deflecting cavity, in the 4 m long glove box. Here it is not possible to maintain such clean experimental conditions as in the measurements mentioned above. To investigate the effect of this restriction we made two experiments, the results of which are shown in Table I as No.8 and 9. Although the Q-values and breakdown fields are slightly less than in the previous measurements the performance is quite satisfactory.

Investigation of surface contamination by X-Ray Photoelectron Spectroscopy

In addition to the cavity measurements we made some experiments on Nb samples which were treated in the same way as the cavities. In order to find the chemical composition of the surface we used X-Ray Photoelectron Spectroscopy (XPS)[12]. We found that our surface treatment procedure results in very clean surfaces, for instance the contamination with sulfur and fluor (HF and H_2SO_4 are used during the chemical treatment) is below the detecting limit of about 1/100 monolayer (~$5 \cdot 10^{12}$particles/cm^2). On the other hand an oxide layer of about 15 Å is always found even after the heat treatment under our conditions. The oxide consists mainly of Nb_2O_5 and increases by storing in air to 25 Å in two days and to 35 Å in 10 days. Storing in nitrogen with a impurity content of less than 5 ppm Oxygen, Water, and Argon and less than .5 ppm carbohydrates increases the oxide layer only by 4 Å (appr.1 monolayer) in 14 days.[13]

IV. RF joint

As a result of earlier tests[2] we used a Nb ring as shown in Fig.5a between the sections and pressed the contacting planes against the ring with stainless steel clamps. This system worked satisfactory in many experiments although the results became poorer, the more often a cavity was assembled, because it could not be avoided that the ring made a groove into the contacting planes. Once the groove was deep enough (.1 mm) the joint became poor. We made a series of experiments to overcome this difficulty by different shapes of the ring and the clamps, but we only could restore the previous results by remachining the contact planes. As this cannot be repeated too often we used joint rings with different contacting

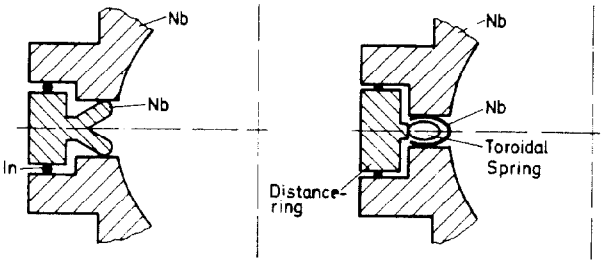

Fig.5a: Niobium joint ring geometry
5b: joint ring with toroidal spring, surrounded by niobium sheet.

diameters. In addition to the experiments mentioned so far, we investigated a new kind of joint rings which are manufactored by [14]. A stainless steel spring of 2.5 mm diameter is wound in toroidal form and surrounded by a .5 mm niobium sheet. This ring is more elastic than the old joint and preliminary results on small cavities are very encouraging.

V. Conclusion

Rf-tests on two combined deflecting cavity sections revealed three difficulties: We found in some cases a poor rf contact at the joint between the sections; due to storing one section under air a deterioration of the surface resistance was observed; in the last experiment a bad spot in one of the coupling cells was the reason for the low Q-values measured. In separate joint experiments we were able to improve the rf contact, and an investigation of the cavity behavior after exposing the surface to several gases solved the storage problem. The defect in the coupling cell remains for further investigation. The gas exposure measurements have shown that a deflecting cavity assembled in a glove box which is flooded with nitrogen gives satisfactory results. Letting down a previously evacuated cavity with clean, filtered nitrogen or argon and subsequent storing under one of these gases for up to 6 days does not affect the performance. After application of electric fields of the order of 30 MV/m a subsequent gas exposure can deteriorate the cavity. By investigation of the surface using X-Ray-Photoelectron Spectroscopy we found quantitative ansanswers about the growth of the oxide layer when the cavity is stored in nitrogen or in air.

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