Investigations on Superconducting 3GHz Nine-cell Accelerator Cavities

D.Reschke, W.Diete, B.Fischer, G.Müller, H.Piel, J.Pouryamout, R.W.Röth
Fachbereich Physik, Bergische Universität Wuppertal, Germany

Abstract

Superconducting linear colliders with beam energies beyond 100 GeV require accelerating gradients of at least 15 MV/m. To achieve such high field strengths in nine-cell structures, we chose an optimized cell shape and high purity sheet niobium (*RRR* > 280). Four nine-cell cavities were heat treated in UHV at 1350 °C with a titanium shield. The results of test series on the achievable accelerating field and Q_0 values will be reported. A high resolution temperature mapping system shows the local distribution of power dissipation and allows a better characterization of the loss mechanism.

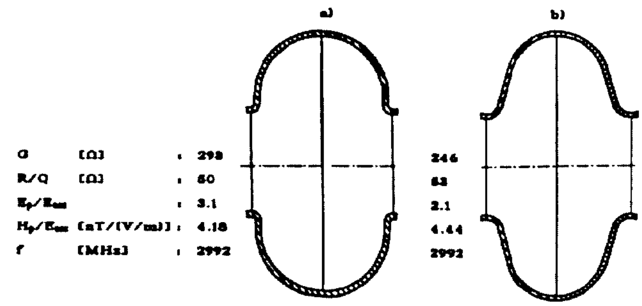

Figure 1: RF-parameters of a) 5-and 20-cell cavity for SDALINAC b) 9-cell TESLA prototype

1 INTRODUCTION

e^+e^--collision experiments in the energy range beyond that of LEP II should be explored by the use of linear colliders. The high Q-values of superconducting (SC) cavities give fundamental advantages to achieve the requirements in luminosity, compared to linear colliders based on warm cavities. The TESLA collaboration was founded in 1989 [1] to prove the feasibility and develop the parameters of such an accelerator. The design of TESLA is based on accelerating fields (E_{acc}) of 15-25 MV/m at Q-values of $(3-5)\times 10^9$ in 1.3 GHz nine-cell structures [2]. As model structures, four nine-cell S-Band prototypes with an optimized ratio of $E_{peak}/E_{acc} = 2.1$ (Fig.1) were built [3]. To develop and optimize usefull technologies for surface cleaning and dustfree mounting, this choice of frequency makes best use of the available infrastructure at Wuppertal and will allow beamtests of the structures in the 130 MeV recyclotron S-DALINAC at the TH Darmstadt.

The improvements of preparation, dust free assembly and processing techniques [4, 5] shifted the limits of E_{acc}, caused by anomalous loss mechanisms like field emission and quenching at local defects, to values above 20 MV/m, even in first multicell cavities [6, 7]. Firing above 1200 °C in an UHV furnace is well known to suppress fieldemission [8, 9] and to result in an effective surface cleaning [8]. To prevent the pick-up of residual gases from the furnace vacuum, which would lower the thermal conductivity, the in-situ solid state gettering by evaporated titanium on the outer side of the cavity was successfully developed [6, 10, 11]. The single-sided titanisation (SST) at 1300-1500 °C of the cavities combines the increase of the thermal conductivity, preventing local and global thermal breakdown, with the reduction of fieldemission. In addition, as shown at Cornell, the remaining field emission can be reduced during the cryotest by the use of short ($\leq$ 1 ms), high power RF-pulses (HPP) [12]. One of the most important challenges for the applicability of SC cavities for linear colliders is to prove the reliability of high gradients in multicell structures. We report on test series on four nine-cell cavities prepared by various techniques.

2 FABRICATION, PREPARATION AND EXPERIMENTAL SETUP

The structures were manufactured by deep drawing and electron beam welding from Wah-Chang sheet Nb with a *RRR* of 270 at Cornell University. For the cryotests, the cavities were prepared by standard etching (BCP), rinsing with ultrapure water or dustfree methanol and UHV heat treatment. The final assembly was performed in our cleanroom (class 10-100). RF- and He-processing can be done with 400 W pulse and cw, using an adjustable input power coupler. A rotatable, high resolution thermometry system for superfluid helium is available to detect the temperature distribution of the RF-losses on the outer side of the cavity. Recently, the system was supplemented by a rotatable frame of 54 X-ray detectors to detect the local distribution of the Bremsstrahlung in case of fieldemission.

3 EXPERIMENTAL RESULTS AND DISCUSSION

The detailed preparation procedures and results of the cavities T1-T4 are summarized in Table 1. Present $Q(E)$-curves are shown in Fig. 2 and 3.

To prevent hydride precipitation in the high purity niobium [6, 13], all structures, except cavity T1, have been heat treated before the first cryotest. This resulted in

test	surface preperation	RRR	Q_0^{max} [10^9]	E_{acc}^{max} [MV/m]	$Q(E_{acc}^{max})$ [10^9]	limitation (comments)
T1-a	BCP 80	270	0.1	-	-	hydrids (C)
T1-b	900 °C , 2h	270	11	9.3	1.0	FE, power (C)
			8	15.0	5.0	Q, HPP (C)
T1-c	BCP 15 850 °C , 4h	270	10	10.6	1.4	FE, power
T1-d	BCP 8, SST 1330 °C , 20h	750	11	(13.8)	1.0	FE, power unflat
T1-e	BCP 5 870 °C , 4h	550	12	16.0	1.0	FE, power
T1-f	BCP 5	550	20	14.0	2.0	FE, power (C)
			> 10	19.5	4.0	FE, HPP (C)
T2-a	BCP 25 850 °C , 4h	270	7	8.3	3.0	Q
T2-b	BCP 8; SST 1330 °C , 23h	750	5.3	(7.9)	0.7	FE, power unflat
T2-c	BCP 57 850 °C , 6h	550	11	(10.3)	1.0	FE, power unflat
T2-d	BCP 8; SST 1330 °C , 23h Tun., Meth.	750	6.5 (1.5K)	11.3	-	FE, power at 2.2K (s.f. leak)
T3-a	BCP 60; SST 1330 °C , 18h Tun., Meth.	750	8.5	11.4	0.8	FE, power
T4-a	BCP 65; SST 1330 °C , 15h Tun., Meth.	750	5.6	11.0	1.0	FE, power
T4-b	BCP 12; Tun. 900 °C , 4h	550	1.4	9.0	1.0	FE

Table 1: Results of cryotests of the cavities T1 - T4 SST: single-sided titanisation; BCP 70: 70μm etching; Q: quench; FE: field emission; power: maximum available input power; (C): measured at Cornell; unflat: very unflat field profile; (...): corrected for effective energy gain; Tun., Meth: tuning and methanol rinsing with ultrasonic agitation in cleanroom

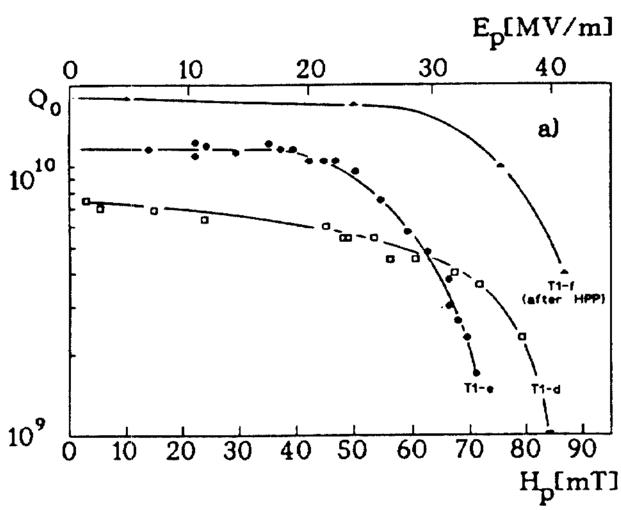

Figure 2: $Q(H_p)$-performance of structure T1

residual quality factors at low fields above $5 \cdot 10^9$, whereas cavity T1 was limited at 10^8 (T1-a) and needed outgassing at 900 °C to achieve high Q-values (T1-b).

After the first heat treatments at 1350 °C (T1-d, T2-b), the mechanical creep of the structures caused a very unflat field profile. Additional fixings in the furnace reduced the problem significantly (T2-d, T3-a, T4-a). Nevertheless, the low wall thickness of 1.6 mm makes the structures very sensitve against detuning during the whole preparation procedure (T2-c). Check and final tuning was performed in the class 1.000-10.000 area of our cleanroom. Before the SST, cavities T1 and T2 were limited by a local thermal breakdown at E_{acc} = 15 MV/m (T1-b) and 8.3 MV/m (T2-a), respectively. In structure T2, the local quench may be due to less etching of only 25 μm, instead of the usual 60 μm, after fabrication. After SST, no thermal breakdown occured up to magnetic surface fields of 90 mT (T1-d,T1-f), as expected for the improved thermal conductivity. As measured on several samples, the RRR increased from 270 to 750. An additional firing at 850 °C without titanium decreased the RRR to 550. Most probably, the reason for the reduced RRR is the pickup of 16 at.-ppm oxygen, both from the furnace vacuum and the Nb_2O_5 surface layer [14], diffusing into the bulk Nb.

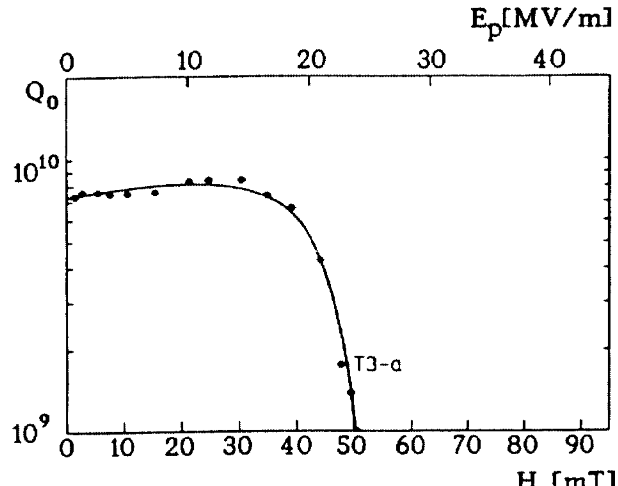

Figure 3: $Q(H_p)$-performance of structure T3

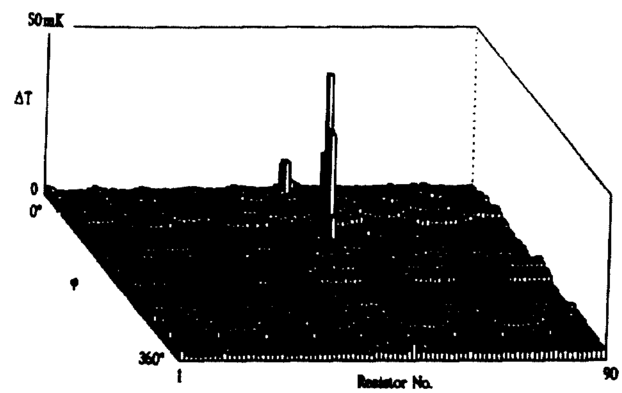

Figure 4: Superfluid temperature map of test T3-a at 10.5 MV/m

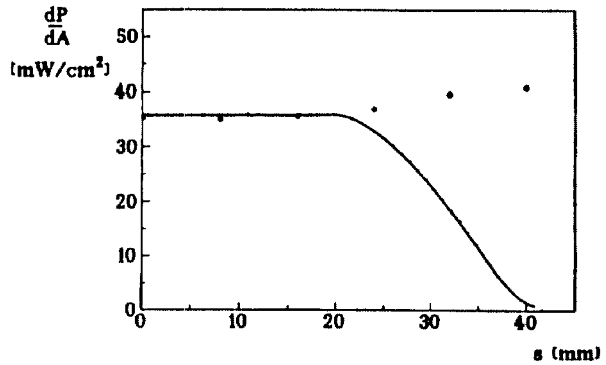

Figure 5: Evidence for dielectric losses at test T3-a

As SST allowed to overcome the local thermal breakdown, fieldemission was still present and limited the gradient in most experiments at 10-16 MV/m. RF- and He-processing in cw or long pulse (> 10 ms) operation up to 400 W caused typically 20-30% progress in E_{acc} before the emission became stable. During the cryotests T3-a, T4-a and T4-b the thermometry system was available. Fig.4 shows the temperture signals of the 90 thermometers at 73 angle positions, detected in superfluid helium of test T3-a. The temperature map, taken at $E_{acc} = 10.5$ MV/m, shows the dominant emitter at the lower iris of the sixth cell. An additional signal was detected near the upper iris of the fifth cell, most probably due to a new emitter. It can be seen nicely, that, corresponding to results on single-cell cavities [15], the achievable gradient is limited by only one or very few local defects and/or field emitters. A detailed analysis of the data at test T4-a confirm the expected Fowler-Nordheim dependence of the temperature signals.

Fig.5 shows the deviation of the measured losses from the expected H^2-distribution at test T3-a. The data are extracted from the mean temperature signal over all 73 angle positions. The detected distribution gives strong evidence for dielectric losses [15]. The most probable explanation is a contamination of the inner cavity surface with titanium or TiO_2 traces due to the SST. This is supported by a significantly higher residual resistance observed in the experiments after SST, compared to a preparation procedure without titanium (Table 1). Titanium might diffuse into the cavity, because the niobium hats on the cavity ports are not completely closed. In case of closed covers, pumping speed is limited too much and residual losses may be caused by the interaction of the cavity surface with the residual gas atmosphere. Thus, the single sided solid state gettering procedure has to be optimized with respect to the residual resistance.

In the near future we will continue our tests with the cavities T2 and T3 with the priority to the suppression of field emission. The movable x-ray diagnostic system is available, now. It will yield additional information about the character and the distribution of the emission sites. Some of the nine-cell structures will be installed in the S-DALINAC to determine, whether it is possible to maintain $E_{acc} > 15M$ V/m from laboratory results to an accelerator with electron beam.

4 CONCLUSION

Advanced firing techniques and cleanroom assembly resulted reproducebly in accelerating gradients of 10-16 MV/m in 3 GHz nine-cell structures with improved cell shape. Field limitation is not yet caused by thermal quenches, but by FE-loading. Advanced diagnostic systems allowed the localisation and characterisation of the limiting anomalous losses. Further progress needs refined preparation, diagnostic and processing (HPP) techniques on single- and multi-cell cavities. Nevertheless, as far as the cavities are concerned, a superconducting linear collider for beam energies beyond 100 GeV is within reach now.

5 ACKNOWLEDGEMENT

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