Test Results on 3 GHz Structures for a Superconducting Linear Collider

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Abstract

To be attractive for a superconducting linear collider, accelerating structures need to provide gradients of at least 15 MV/m. Recent work shows that such field strengths can be reached reliably in single cell cavities using high purity niobium and clean surface preparation techniques, which include heat treatment in UHV at about 1300 °C. In this paper, we show that the gradients required for a superconducting linear collider can also be reached with 5- and 9-cell structures prepared by these techniques.

INTRODUCTION

Due to synchrotron radiation, e^+e^--annihilation experiments beyond LEP II energies can only be realized with linear accelerators economically. A promising way to build such a collider with a high beam quality is the use of superconducting (SC) cavity resonators, operating below 3 GHz. To proove their feasibility, the TESLA-collaboration was founded in 1989 [1]. Taking into account anomalous loss mechanisms like field emission and quenching at local defects, as well as the fundamental limitation set by the superheating magnetic field [2], the TESLA machine is based on multicell structures with acceleration gradients (E_{acc}) of 15 - 40 MV/m. By systematic improvement of the cleaning and mounting techniques [3], gradients up to $E_{acc} \approx$ 30 MV/m can be reached in single cell cavities made from Nb of high thermal conductivity λ today (Fig.1). A good performance is reached most reliably by firing above 1200°C [2,4,5], since the pickup of residual gases from the furnace vacuum was eliminated by the development of the single-sided titanisation (SST) postpurification technique [6,7], which suppresses defects due to increased RRR values, and reduces field emission [8,9] most probably due to homogenization or evaporation of impurities.

The application of these results to multicell structures was started with 5- and 20-cell resonators for the SC recyclotron SDALINAC at TH Darmstadt [7]. Due to the comparably high electric surface field ($E_p/E_{acc}=3.1$), the gradient in these structures is limited most often by field emission loading. Regarding this fact and the

experience with manufacturing tolerances, field flatness, and surface cleaning as well as the expected HOM-excitation in a linear collider, we decided to build the TESLA prototype structures with 9 cells with an improved cell shape. In this paper we report about the first of these and the best 5-cell resonator.
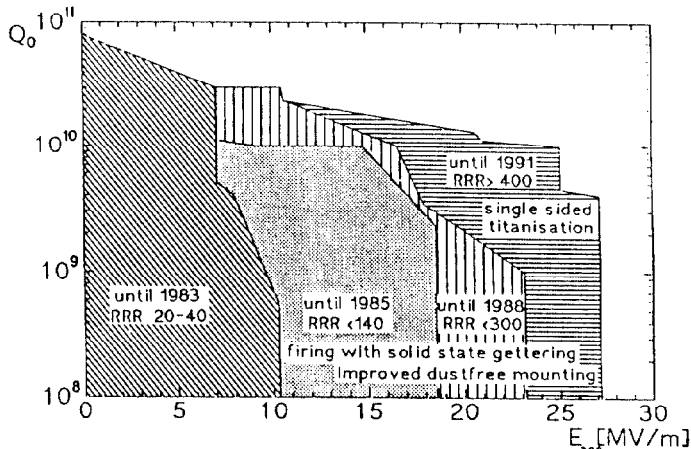

Fig.1: Performance limits of 3-GHz single cell cavities at Wuppertal ($T_{Bath}=1.5$ K). Similar results have been obtained at 1.5 GHz [10].
($RRR \approx 4 \cdot \lambda (4.2$ K) $[W/m \cdot K]$)

FABRICATION AND PREPARATION OF 9-CELL 3-GHZ CAVITIES

The cell shape of the 9-cell TESLA prototype structures was optimized at Cornell University with respect to a small E_p/E_{acc} (Fig.2), using the URMEL code. The π-mode frequency of the structure was chosen to allow acceleration tests in the SDALINAC machine with their high quality electron beam [11]. Four structures have been manufactured from high purity niobium (RRR 270) by deep drawing and electron-beam welding at Cornell.

			a)	b)
G	[Ω]	: 293		: 246
R/Q:	[Ω/cell]	: 100		: 106
E_p/E_{acc}		: 3.1		: 2.1
H_p/E_{acc}	[mT/(V/m)]	: 4.18		: 4.44
f	[MHz]	: 2992		: 2992

Fig.2: RF parameters of a) multicell cavity for SDALINAC b) 9-cell prototype for TESLA

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For the cryotests the cavities have been cleaned by standard etching (BCP), rinsing and vacuum firing techniques [7]. The final mounting was performed in a cleanroom (class 10), to reduce field emission loading due to dust particles.

RESULTS AND DISCUSSION

The results of the tests of our best 5-cell cavity (E5) for SDALINAC and our first 9-cell prototype (T1) for TESLA are summarized in Figs.3 and 4. These data fit well into our statistics with single cell cavities. Initially, with $RRR \approx 40$, the acceleration gradient in the 5-cell cavity never exceeded 5.5 MV/m ($H_p = 23$ mT) due to thermal quenching (e.g.Fig.3a, E5-a). Postpurification by double sided titanisation (DST; 1300°C, 8.5h) [6,12] increased the RRR about fourfold, shifting quenches at typical defects to fields well above $H_p = 50$ mT ($E_{acc} > 12$ MV/m). The necessity to remove the Ti getter layer after DST from the inner cavity surface by wet etching (70 μm BCP) followed by an extensive rinsing sacrifices some benefits of the heat treatment. Especially, the probability for field emission loading increases again [6]. Indeed, the field strength was limited by electron emission in this experiment (E5-b). As expected, a completely dry furnace treatment (SST at 1360°C,18h) in combination with dustfree mounting yielded a field emission free surface up to the quench limit at $H_p = 92$ mT ($E_{acc} = 22$ MV/m) (E5-c). The maximum surface field of $E_p = 68$ MV/m would correspond to an acceleration gradient of 32 MV/m in the TESLA prototype geometry.

The 9-cell cavities were already built from Nb with RRR=270. In the first test of prototype T1 at Cornell, an 80 μm BCP treatment resulted in a residual quality factor of only $Q_{0,res} = 10^8$, due to hydride precipitation in high purity niobium [7]. Outgassing of the cavity at 900°C for 2 h increased $Q_{0,res}$ at low fields to $1.7 \cdot 10^{10}$ (T1-b), but strong field emission starting at about $E_{acc} = 8.5$ MV/m loaded Q_0 to $1.3 \cdot 10^9$ at $E_{acc} \approx 10$ MV/m. As discussed in another paper at this conference [13], RF processing with short pulses of 40 kW (HPP) destroyed the dominating emitters. E_{acc} could be increased now to 15 MV/m ($Q_0 = 5 \cdot 10^9$), where a quench occured (Fig.3b, T1-b(HPP)). Reproduction of the wet treatment and firing at 850°C for 4h at Wuppertal resulted in a comparable cavity performance (T1-c) with strong field emission above $E_{acc} \approx 9$ MV/m as in test T1-b before HPP. In all these experiments the field flatness of the structure was better than ±20%.

To reduce intrinsic field emitters and to allow a completely dry surface cleaning, a SST treat-
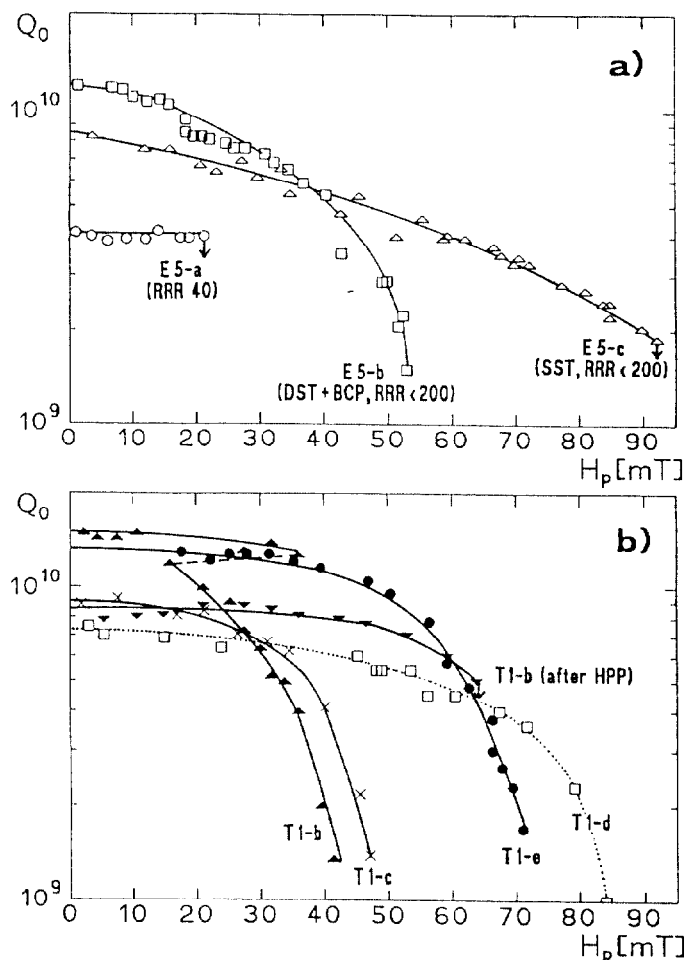

Fig.3: $Q(H_p)$ performance of multicell 3 GHz cavities. a) 5-cell structure for SDALINAC b) 9-cell prototype for TESLA (Details on the preparation are given in the text.)

ment (1330°C, 20h) was performed (T1-d). As expected, the onset field for field emission was increased significantly and the quench limitation at $H_p = 67$ mT disappeared (supposed RRR<700). However, the field profile became unflat during firing due to the mechanical creep of the structure, resulting in a factor $E_{max}/E_{min} = 4.2$. In future, we plan to introduce additional fixtures during the furnace run to prevent creeping. In test T1-d, however, the field was concentrated mainly at one end of the structure, where a surface field of $H_p = 84$ mT ($E_p = 38$ MV/m) was reached. This performance is plotted in Fig.3b as dotted line. The energy gain of an electron accelerated in this structure would have been U=5.7 MV. After tuning the cavity fieldflat and firing at 870°C (T1-e), U increased to 7.2 MV, while the maximum field strength was limited at a comparable value ($E_{acc} = 16$ MV) by field emission loading of similar strength as in test T1-d.
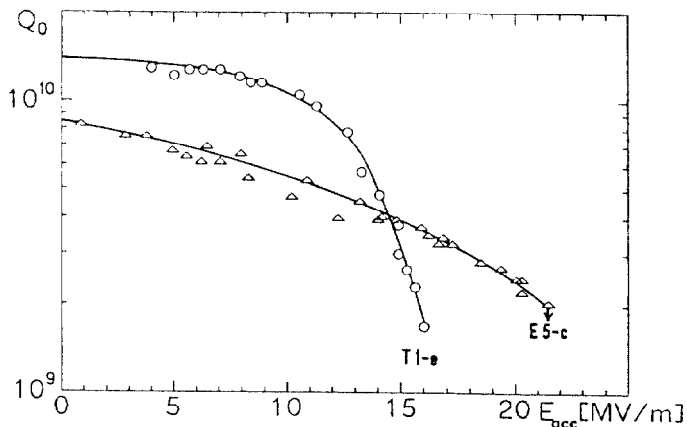
Fig.4: Performance of 9- and 5-cell cavity
after heat treatment

It is remarkable how the achievable quality factor depends on the cavity preparation technique and on the field strength. Multicell cavities of low purity and of a shape like in Fig.2a, which were never fired, show the lowest Q_0 (Fig.3a, E5-a). Firing above 1850°C have yielded redidual Q_0 values up to $8 \cdot 10^{10}$ (Fig.1). DST and SST at medium temperatures of about 1300°C result in Q_0 values around 10^{10}, depending on the vacuum conditions in the hot zone of the furnace (Figs.3, 4). With increasing field strength, the quality factor is reduced by field emission loading and/or by the field dependence of the residual resistance. This is disadvantageous, because Q_0 values of above 10^{10} will be necessary to reach field levels above $E_{acc} = 30\,MV/m$ at 3 GHz, as shown by model calculations [2]. Thus, for a deeper understanding and the reduction of the anomalous loss mechanisms, additional test series on advanced preparation techniques (e.g. firing at higher temperatures or electropolishing) are underway with single-cell cavities.

For the further improvement of the multicell structures, it is most important to suppress field emission better. To allow a more effective rf- and He-processing, an adjustable input coupler will be added to the 9-cell cryostat insert soon. Diagnostic systems for x-ray mapping and thermometry in superfluid helium are forseen for a guided repair of the structures in the future. The full application of class 10 dustfree mounting should help to eliminate emission from loose particles on the surface. Nevertheless, acceleration gradients of about 20 MV/m and quality factors of about $3 \cdot 10^9$, as they are needed for the first stage of the TESLA machine, can be reached with the best multicell cavities already (Fig.4).

In the near future, we plan to heat treat and test all four 9-cell structures to improve the statistical significance of the results achieved so far. Some of the structures will also be installed in the SDALINAC accelerator to determine whether it is possible to maintain $E_{acc} > 15\,MV/m$ from laboratory results to an accelerator with beam.

CONCLUSION

We have shown that the improvements on the performance of single cell Nb cavities made during the last 5 years by advanced dustfree mounting and firing techniques can be successfully transferred to multicell structures. Acceleration gradients of 22 MV/m in the best 5-cell and of 16 MV/m in the first 9-cell cavity of improved cell shape have been achieved. The increase of E_{acc} beyond 25 MV/m needs additional investigation on single cell cavities. Nevertheless, superconducting accelerators are a promising option to build a linear collider for electrons with beam energies in excess of 300 GeV already now.

ACKNOWLEDGEMENT

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