PRODUCTION OF SUPERCONDUCTING 9-CELL CAVITIES FOR THE TESLA TEST FACILITY, STANFORD UNIVERSITY AND FORSCHUNGSZENTRUM ROSSENDORF

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Abstract

Since 1995 ACCEL has built 15 superconducting niobium 1.3 GHz 9-cell cavities for the TESLA Test Facility. In addition 25 more such cavities are under production. For Stanford University 5 cavities and for the ELBE project at Forschungszentrum Rossendorf 6 cavities of the TESLA design have been produced. After the vertical tests carried out at DESY, the Stanford and Rossendorf cavities were equipped with the helium tank at ACCEL. The required helium tanks were built following the TESLA approach and redesigned in order to fit the different boundary conditions, The cavities now routinely reach accelerating gradients in the 20-30 MV/m regime with quality factors above $5{\cdot}10^9$ in vertical tests at a bath temperature of 2.0 K. Horizontal test have been carried out on some cavities without any performance reduction. During the horizontal tests the cavities are equipped with all auxiliary components.

1 INTRODUCTION

Among the several worldwide designs which are under development for a next generation e^+e^--linear collider in the 500 GeV to 1 TeV energy regime, TESLA [1] is the only approach which uses superconducting cavities for acceleration. The present design is based on 1.3 GHz 9-cell cavities with an accelerating gradient of $E_{acc} > 25$ MV/m and a quality factor Q_0 above $5{\cdot}10^9$. The main design parameters of the TESLA 9-cell superconducting cavity are listed in table 1.

Table 1: Main design parameters of the superconducting TESLA cavity [1]

Resonant frequency	1300 MHz
Number of cells	9
Cell to cell coupling	1.87 %
$R/Q = V_{acc}^2/(P_{diss}{\cdot}Q_0)$	1036 Ω
Geometry factor G	270 Ω
E_{acc}	> 25 MV/m
Q_0	$> 5{\cdot}10^9$
E_{peak}/E_{acc}	2.0
B_{peak}/E_{acc}	4.26 mT/(MV/m)
Iris diameter	70 mm
Equator diameter	206.6 mm
Active length	1.038 m

Besides for a high energy linear collider a second application of such cavities are to serve for acceleration in Free Electron Lasers (FEL's) including future 4th generation light sources [1], [2].

The theoretical limit of the gradient of superconducting niobium cavities is given by the critical magnetic field of niobium. This value is about 200 mT, and therefore an accelerating gradient of about 50 MV/m should be possible in TESLA 9-cell structures. Major improvements in cavity performance have been obtained in the last 10 years by minimizing the dust contamination of the inner surface of the cavities mainly by a technique called high pressure rinsing and by improvement of the purity and hence thermal conductivity of the niobium. The RRR value of the niobium, the ratio of resistivity at room temperature and at 4.2 K (with the niobium in the normal conducting state by applying a high magnetic field) is a good indicator of the purity and is linear to the thermal conductivity λ at 4.2 K. Today niobium with a RRR of 300 is industrial standard.

As one approaches now accelerating gradients above 25 MV/m even in multicell structures, one comes closer to the theoretical limits and therefore the manufacturing process becomes more and more critical.

Beside the RF properties, also the mechanical properties are of great importance when the cavities have to be put into the accelerator. It is necessary to achieve both, the right frequency and the right mechanical length of the cavities. In order to have good damping of the higher order modes (HOM), the exact shape of the cells must be fabricated with high accuracy.

2 PRODUCTION STEPS

2.1 *Niobium cavity*

The cavity is produced by electron beam weld cups which are deep drawn from niobium sheets of 2.8 mm thickness. The deep drawing die is made out of aluminum. The exact form of the cups after the deep drawing process depends on the used niobium material. The hardness and the grain size of the niobium sheets are of importance and can vary depending on the last annealing steps of the sheets. It has been observed, that differently produced niobium sheets are behaving differently in forming and welding.

During the manufacturing process, all parts which have to be electron beam welded need to be cleaned by buffered chemical polishing using BCP 1:1:2 (a mixture of the following acids: 40 % HF, 65 % HNO_3, 85 % H_3PO_4 in the volume relation 1:1:2). Every electron beam weld needs to be visually inspected and leak-checked. It is worth to mention, that the major work hereby is concentrated in the two so called endgroups. An endgroup is shown in Fig. 1. One endgroup has ports and flanges for the beam pipe, the main input coupler and a HOM coupler, the other endgroup has ports and flanges for the beam pipe, the pick up flange and the second HOM coupler. Other parts of both endgroups are the conical head plates on which the helium vessel is welded after the successful vertical test and the reference flange which is also needed to assemble a mounting frame around the completed cavity in order to give mechanical stability during evacuation of the cavity.

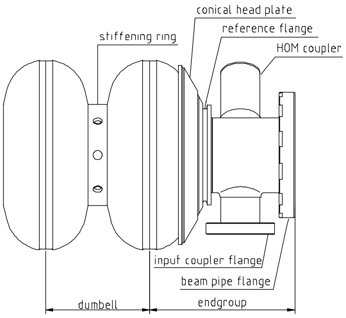

Figure 1: Endgroup section and stiffening rings of the TESLA 9-cell cavity.

The manufacturing of the cells is complicated by the fact, that stiffening rings have to be welded in the iris region (see Fig. 1). The stiffening rings are needed to counteract against the Lorentz Forces, which detune the cavity when operated in the pulsed mode. In a cw machine they would not be necessarily required. The welding of the stiffening rings introduces problems in achieving the exact shape, because the cells get deformed somewhat by this production step.

The cups and the dumbells (two cups welded together on the iris and furnished with stiffening rings) are checked by frequency measurements and eventually machined prior to the next manufacturing step in order to get the right frequency and the right length of the completed resonator.

With the present fabrication technology developed together in a close collaboration with DESY, the cavities achieve now both, the required mechanical accuracy and an excellent RF performance as detailed below.

2.2 *Helium vessel*

For the cavities built for Stanford University and for Forschungszentrum Rossendorf, ACCEL has also produced the required helium vessels. The vessels were adopted from the TESLA approach but redesigned in order to fit the different boundary condiditons. The vessels are made out of titanium. A titanium ring and a titanium bellow are electron beam welded to the conical head plate of the cavity after successful vertical test. The vessel itself is then also electron beam welded to the bellow and the ring. This bellow allows to tune the cavity still after it is welded to the helium tank.

A picture of the naked TESLA type cavity and a cavity dressed with helium vessel is shown in Fig. 2.

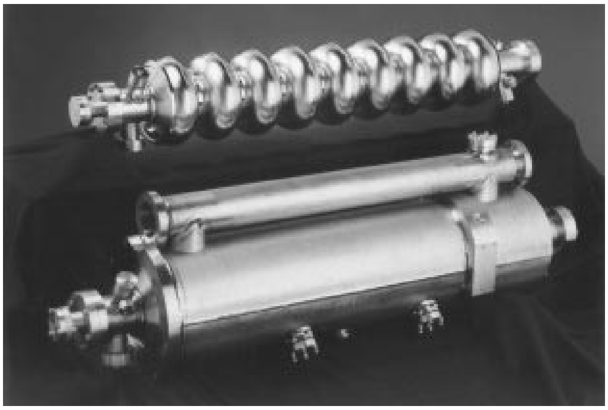

Figure 2: TESLA type 9-cell niobium cavity produced by ACCEL. In the background the naked cavity is shown, in the foreground the cavity is already equipped with its helium vessel produced by ACCEL according to the specific Stanford and Rossendorf design.

3 CAVITY TEST RESULTS

After fabrication at ACCEL the cavities are chemically prepared and tested at DESY. Since 1995 26 TESLA type cavities which were produced by ACCEL have been tested in a vertical cryostat at DESY. The average gradient achieved in this 26 cavities was 20.5 MV/m [3].

As an example, what can be achieved with the present fabrication and preparation technique, the results obtained in vertical tests of the second cavity production run for the TESLA Test Facility (TTF) at DESY are listed in table 2. On average a gradient of 26.5 MV/m was achieved [3]. Only one cavity showed a quench below 25 MV/m. All other cavities reached more than 25 MV/m with quality factors above $5 \cdot 10^9$. Most of the cavities are not limited by a quench but by available RF power. One can therefore conclude, that already with the present technology of electron beam welded niobium 9-cell structures, the required gradients and quality factors for TESLA can be achieved on a routinely base.

Table 2: Accelerating gradients E_{acc} and quality factors Q_0 achieved during vertical tests at DESY in superconducting niobium 9-cell cavities of the second production for the TESLA Test Facility [3].

Cavity	E_{acc} [MV/m]	Q_0 [10^9]	Limitation
S28	25.3	6	RF power
S29	26.7	6	RF power
S30	28.4	8	RF power
S31	28.1	5	Quench
S32	28.1	7	RF power
S33	25.5	5	RF power
S34	28.4	6	Quench
S35	21.2	15	Quench
S36	26.6	8	RF power
Average:	**26.5**		

A typical excitation curve (measurement of the quality factor Q_0 in dependence of the accelerating gradient E_{acc}) of a good 9-cell cavity is shown in Fig. 3. The measurement was performed at a bath temperature of 2.0 K. It is remarkable that the quality factor at a gradient of 25 MV/m is still above 10^{10}.

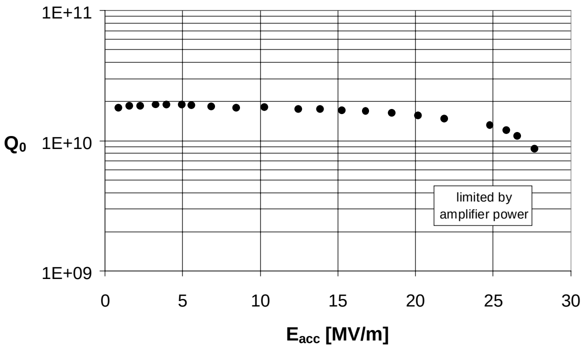

Figure 3: Vertical test result of cavity S30 at a bath temperature of 2.0 K [3]. The cavity was limited by available RF power.

In addition some cavities were measured also fully equipped with all auxiliary components in a horizontal cryostat. Here the measured performance was basically the same as in the vertical test. Eight cavities have been installed in the TTF linac. They are working there without any obvious performance degradation.

4 OUTLOOK

In the moment 25 more 9-cell cavities are under production at ACCEL for the TESLA Test Facility. The cavities will be delivered to DESY until summer 2000.

If TESLA will be built, 20000 cavities need to be manufactured in about 3 years. For production of such a high number of cavities, mass production logistics have to be applied with the goal of significant reduction of production cost. In parallel the present fabrication technology should be analyzed to identify cost drivers in the cavity production.

5 ACKNOWLEDGEMENT

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5 REFERENCES

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