RESULTS FROM A 850 C HEAT TREATMENT AND OPERATIONAL FINDINGS FROM THE 3 GHZ SRF CAVITIES AT THE S-DALINAC*

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Abstract

Reaching the design quality factors and lowering the residual losses of the cavities at the superconducting electron linac in Darmstadt (S-DALINAC) is still an ongoing activity. After installation of an UHV furnace in Darmstadt two years ago, six cavities have now been heat treated at 850 C to remove residual hydrogen from the niobium cavity surface. A gas analysis during the heat treatment procedure showed that the cavities were strongly contaminated which might explain the low Q. We will report about the furnace, the heat treatment procedure and the results of subsequent surface resistance measurements. Prior to the heat treatment the field flatness of the 20 cell elliptical cavities was measured leading to unexpected results: After almost 10 years of operation, the field flatness of some cavities was heavily distorted. This might be an indication that the frequency tuning of the cavity, which is done by compressing the cavity longitudinally, does not act uniformly on each cell even though the cavity is only supported at the end cells.

INTRODUCTION

The superconducting Darmstadt electron linear accelerator S–DALINAC was put into operation in 1987. It consists of twelve superconducting 20 cell niobium cavities, operated at 2 K at a frequency of 2.9975 GHz. With a design accelerating gradient of 5 MV/m and a design quality factor of $3\cdot10^9$ in cw operation, the final energy of the machine is 130 MeV which is reached when the beam is recirculated twice [1]. The layout of the S–DALINAC is shown in Fig. 1.

The first set of cavities was built in the 80's at Interatom using low RRR material, so the observed performance regarding the gradient and the quality factor was rather poor [2]. Accordingly, a second set of cavities was ordered in the 90's made from RRR 300 material.

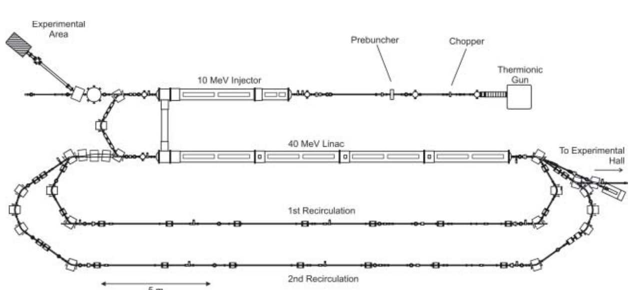

Figure 1: Floor plan of the S-DALINAC.

These cavities, welded at Dornier, are used since then. All of them reach the design gradient, some exceeding it by more than 50 % [3]. Unfortunately the accelerator does not benefit from this improvement: Due to the limited refrigerator power of some 100 Watt and the rather low Q of the cavities (typically below $1\cdot10^9$) the cavities have to be operated below their maximum gradients. The final energy of the accelerator in cw operation therefore never exceeded 90 MeV. So reaching the design energy of 130 MeV is still a matter of achieving higher quality factors. Many measures have been taken in the past and reported at the srf-workshop [4], all of them helped improving the Q but none was able to solve the problem completely. This paper describes the results of an 800 C heat treatment of the cavities.

CAVITY FIRING

The high temperature vacuum firing has proven to be an inherent part of the surface preparation of superconducting cavities. This procedure is applied to stress anneal the niobium and to remove hydrogen from the material inoculating cavities against the "Q disease" during their operation. The S-DALINAC niobium cavities were heat treated at 750 C after their commissioning as well. However recent studies have shown that the niobium is still contaminated by hydrogen, requiring a renewed treatment of the cavities.

A high temperature vacuum furnace shown in fig. 2 allowing temperatures of up to 1800 C was put into operation at Darmstadt in 2005. Its construction and basic parameters are described in [5]. Until summer 2006, a total of 6 cavities were prepared according to the following procedure:

- field flatness measurement/ tuning
- ultra sonic cleaning
- oxidation of the cavity surface using HNO_3
- rinsing with ultra-pure water
- removing the oxide layer with HF
- rinsing with ultra-pure water
- drying by vacuum pumping
- heating to 800 C inside the newly installed UHV furnace
- venting with nitrogen
- reinstallation into the accelerator
- cool-down and Q-measurement

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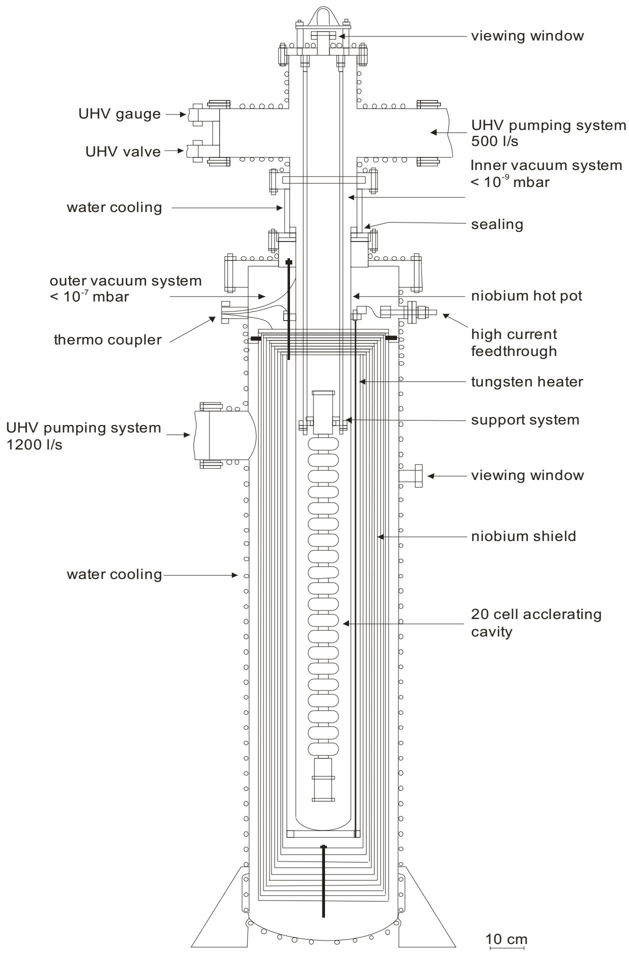

Figure 2: Side view of the UHV furnace originally built and operated in Wuppertal[5], now relocated to Darmstadt.

More details on the exceptional findings when measuring the field flatness will be reported in the next section. Once the cavity was mounted inside the furnace, the temperature was increased steadily up to 800 C, keeping the vacuum pressure below $1{\cdot}10^{-5}$ mbar. The residual gas in the furnace was analyzed using a mass spectrometer; the temperature was measured with a pyrometer. The heat treatment procedure lasted typically 8 to 10 days. A typical temperature and gas profile is shown in fig. 3.

By taking the throughput of the ion getter pump, the integrated partial pressure and the amount of niobium, a hydrogen contamination of the cavity of some 60 ppm could be estimated values above 2 ppm are thought to cause Q-disease [6]. After the heat treatment, the cavities were taken out of the furnace and mounted directly without any intermediate preparation step, which could be

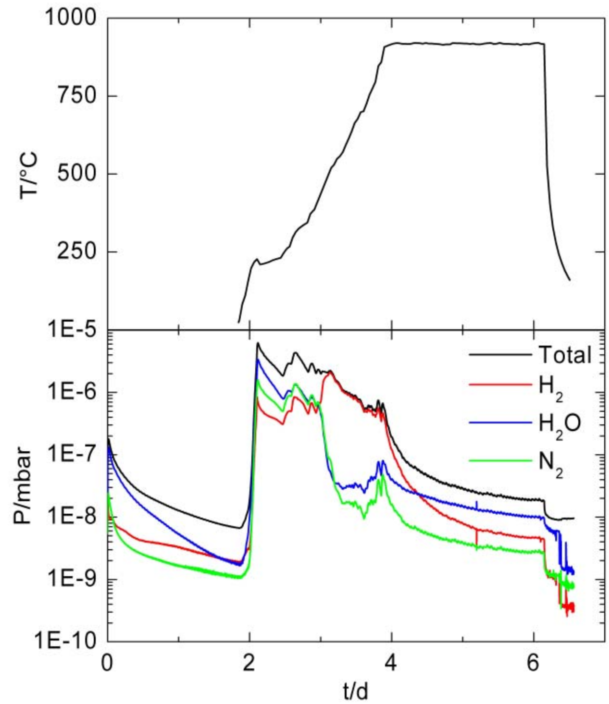

Figure 3: Temperature and partial pressure of the residual gas inside the furnace during the firing procedure. At 300 C hydrogen becomes dominant indicating a huge reservoir.

questioned. After cooling down to 2 K, the quality factor was determined. As can be seen in fig. 4 the cavity improved from $7{\cdot}10^8$ to $1.5{\cdot}10^9$ by this treatment beeing still below design. Unfolding the contributions to the quality factor via

$$R_s = \frac{G}{Q_0} = R_{BCS} + R_{mag} + R_{res} \,,$$

where R_{BCS} denotes the surface resistance as predicted by BCS theory, R_{mag} is the additional resistance expected due to frozen magnetic flux- in our case measured to be 1/3 of the earth magnetic field leading to a residual resistance of 60 nΩ (see tab. 1).

Table 1: Contributions to the surface resistance deduced out of the measurement shown in fig. 4.

Q_0	$1.6{\cdot}10^9$	R_{BCS}	58 nΩ
G	275 Ω	R_{mag}	54 nΩ
R_s	172 nΩ	R_{res}	60 nΩ

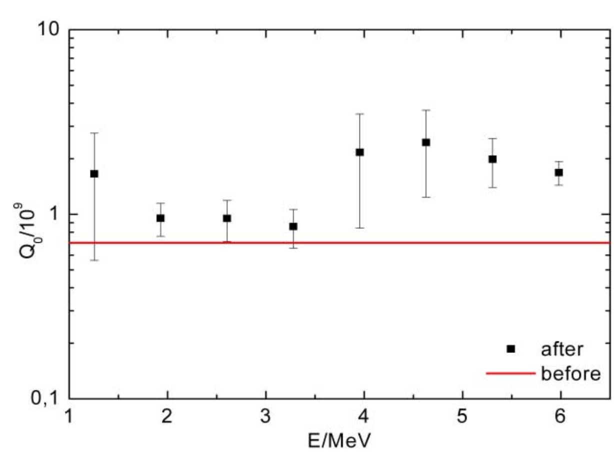

Figure 4: Measured quality factor before and after the heat treatment.

For cavities contaminated with hydrogen a high residual resistance would be expected, but for cavities fired at 800 C lower values are anticipated.

Out of the data two objectives can be deduced: First, the contribution coming from the frozen magnetic flux is in the order of the BCS value. This has to be improved by adding additional shielding against the earth magnetic field. Second, the residual resistance is even higher and exceeds values achieved elsewhere by far. This indicates that the process of preparing and/or mounting of the cavities still needs to be improved, for example by applying an HF polishing after the heat treatment. Both will be addressed in the future.

FIELD FLATNESS CHANGES

When the cavities had been installed more than 10 years ago, all cavities were tuned to a flat field profile to ensure optimum performance. During operation, continual measurements of the pass band frequencies indicated a change in the field flatness profile which only could be quantified by dismounting the cavities. Before the cavities were heat treated, a profile was measured with a bead-pull measurement set-up. One typical example is shown in fig. 5. Obviously, the field flatness was heavily distorted after several years of operation, which cannot be explained so far.

During operation the cavity frequency is adjusted by a tuner (shown in fig.6) changing the overall length of the cavity. This tuner acts on the cut-off tubes of the cavity only, while the elliptical cells hang freely in between. This should lead to a uniform distribution of the forces along the cavity and thus to an undisturbed field profile.

The measurement shown in fig. 5 suggests that the tuning force does not act uniformly over the cavity length which might be caused by two reasons. One could be that there is some friction between the cavity support frame and the cavity reducing the forces from cell to cell. The other reason which seems to be more attractive is that the elliptical cells have different spring constants making the cavity itself mechanically inhomogeneous.

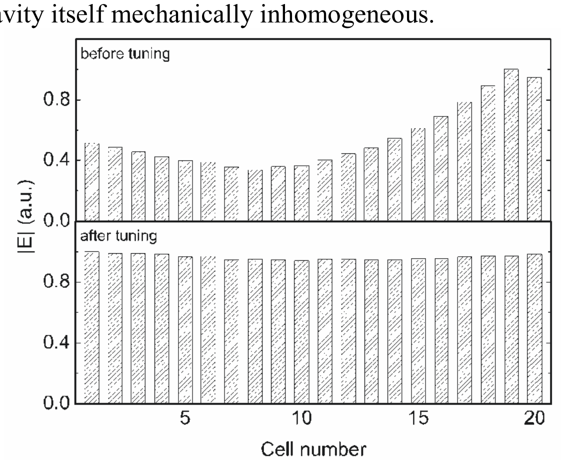

Figure 5: Measured field flatness of one cavity being in operation for more than 10 years. The heavily distorted field profile could be restored during the tuning procedure.

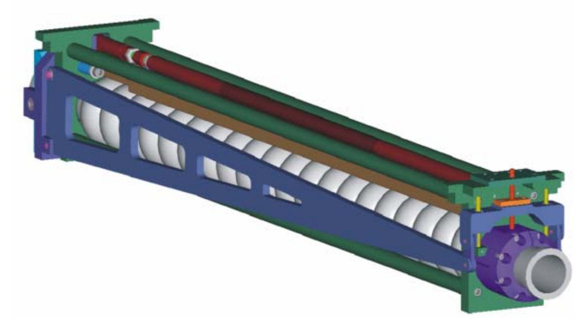

Figure 6: Isometric view of the cavity tuner. The frequency change is provoked by pushing or pulling on the cavity cut-off tubes. The cavity in between is not supported nor hindered in its movement.

Investigations on this findings will go on, however it could be stated that our way of tuning the cavity by changing the total length – commonly used in other places too – in our case leads to unwanted distortions in the field profile.

OUTLOOK

The performance of the 3 GHz cavities in Darmstadt is still below design, limiting the accelerator operation. Measures to improve especially the cavity Q will proceed in future activities. Nonetheless, two new cavities will be ordered, fabricated with state of the art technology, hopefully revealing the reasons for the unexplained high losses.

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