IMPROVING THE SUPERCONDUCTING CAVITIES AND OPERATIONAL FINDINGS AT THE S-DALINAC*

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Abstract

After 15 years operating the S-DALINAC the design quality factor for the superconducting cavities has still not been reached. Currently, the cavities are heat treated at 850 C in an UHV furnace installed in Darmstadt three years ago. 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 some of the 20 cell elliptical cavities has been measured, leading to unexpected operational findings to be reported: operating and frequency-tuning the cavity for several years led to heavy distortions of the field flatness. This might be an indication that the frequency tuning of the cavity done by compressing the cavity longitudinally, does not act uniformly on each cell even though the cavity is only supported at the end cells. The paper will close with a status report on machine operation and modifications undertaken during the last two years.

INTRODUCTION

The superconducting Darmstadt electron linear accelerator S–DALINAC was put into operation in 1987. It consists of ten 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 $3{\cdot}10^9$ 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.

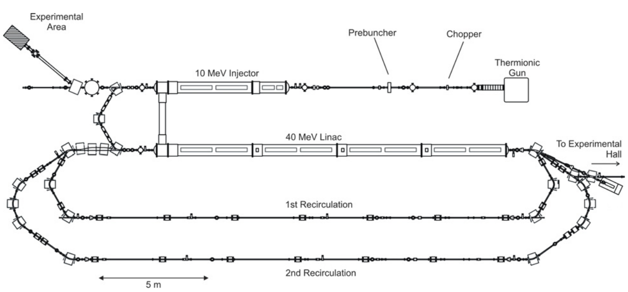

Figure 1: Floor plan of the S-DALINAC.

These cavities, welded at Dornier, are used since then. All of them reach the design gradient, some exceeding it by more than 50% [3]. The accelerator performance however did 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 $1{\cdot}10^9$) the cavities have to be operated below their maximum gradients. Many measures have been taken in the past [4], all of them helped improving the Q but none was able to solve the problem completely.

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 which can be explained by doubting the temperature measurement during the first firing.

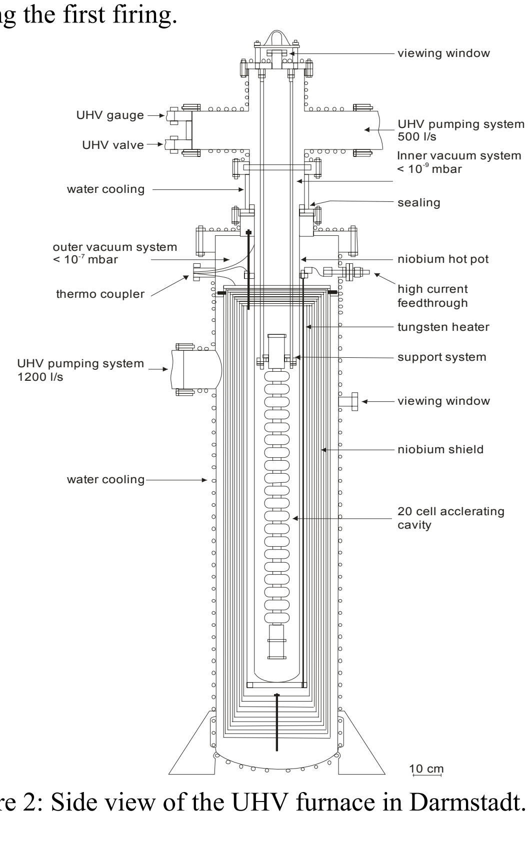

Figure 2: Side view of the UHV furnace in Darmstadt.

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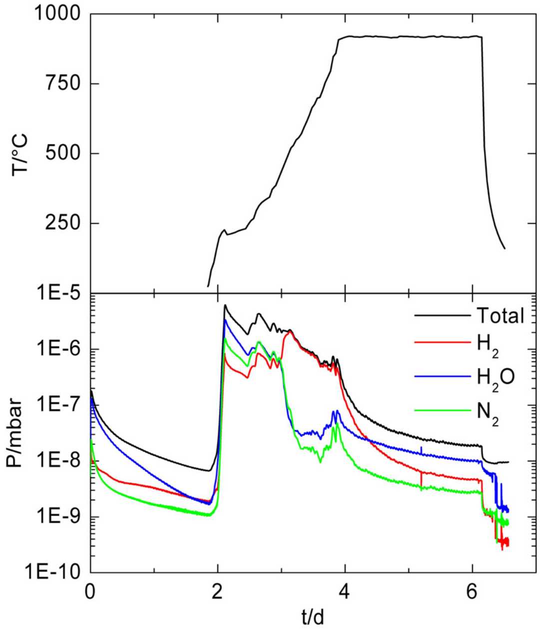

Figure 3: Temperature and partial pressure of the residual gas inside the furnace during the firing procedure. At 300 C hydrogen becomes dominant indicating a huge reservoir.

The high temperature vacuum furnace shown in Fig. 2 allows temperatures of up to 1800 C. It was put into operation at Darmstadt in 2005 after relocation from Wuppertal. Its construction and basic parameters are described in [5]. Up to now a total of 7 cavities were heat treated.

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 30 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 inside the accelerator cryostat without any intermediate preparation step. After cooling down to 2 K, the quality factor improved from $7 \cdot 10^8$ to $1.5 \cdot 10^9$ by this treatment being still below design. Unfolding the contributions to the quality factor leads to a residual resistance of 60 nΩ.

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 need to be improved, for example by applying a hydrofluoric acid 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 field profile which only could be quantified by dismounting the cavities. So before the cavities were heat treated as described above, a field profile was measured with a bead-pull measurement set- up. The field distribution of six cavities measured so far is shown in Fig. 4.

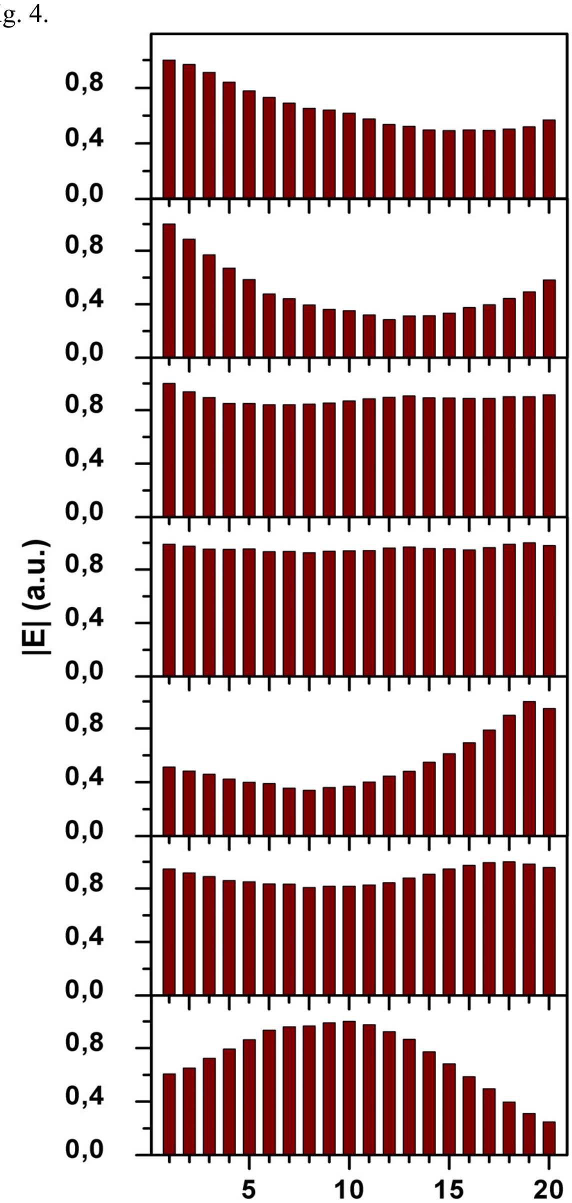

Figure 4: Measured field flatness of six cavities being in operation for some 10 years. Some cavities display a heavily distorted field profile that could be restored during the tuning procedure.

Obviously, the field flatness of some cavities is heavily distorted after several years of operation, while other cavities are still more or less field flat.

During operation the cavity frequency is adjusted by a tuner changing the overall length of the cavity. The 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, which seems to be true for some cavities but wrong for the others (with distorted field profile). The measurement shown in Fig. 4 suggests that the tuning force does not act uniformly over the cavity length for all cavities, which might be caused by two reasons: Some friction between the cavity support frame and the cavity reducing the forces from cell to cell might be one explanation. The other, which seems to be more attractive, is that the elliptical cells have different mechanical spring constants making the cavity itself mechanically inhomogeneous.

Investigations on this findings will go on, however it could be stated that 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 differing from cavity to cavity.

However, all cavities could be retuned to a flat field profile by squeezing the individual elliptical cells.

COLD LEAK PROBLEMS

During last year's operation, several cold leaks developed, degrading the cavity performance and disrupting the accelerator operation. After several time consuming investigations the reason for these cold leaks could be determined: The HELICOFLEX® gasket used to seal the cavity flange against the coupler (see Fig. 5) became untight, especially after an insitu-baking procedure followed by an immediate cool-down to 2 K. After checking all parameters to lie within specifications the reason for this was localized: the HELICOFLEX® gasket made out of aluminum was hard enough to cave the flat cavity flange (made out of RRR30 Niobium) after many years of operation, some 50 thermal cycles and approximately 10 replacements of the gaskets. As the tightness of this gasket is ensured by pressing it to a nominal thickness which is ensured by a nose-piece in the coupler flange, the score mark in the cavity flange reduces the compression of the gasket and thus explains the failure in tight sealing.

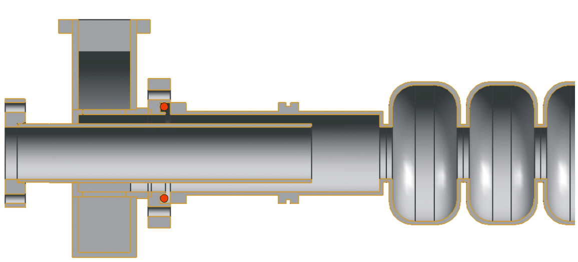

Figure 5: Cross section of the coupler to cavity transition. The HELICOFLEX® gasket used is marked red.

Currently, all HELICOFLEX® gaskets are replaced by gaskets with overmeasure (by adding the depths of the score to the gasket thickness), not solving the principle problem but ensuring tightness without machining the ultraclean surface of the cavity or the coupler.

Figure 6: Picture of the cavity flange displaying an obvious score mark.

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