

SECOND-SOUND MEASUREMENTS ON A 3 GHz SRF CAVITY AT LOW ACCELERATION FIELDS*

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Abstract

The superconducting Darmstadt electron linear accelerator S-DALINAC uses 20-cell niobium cavities that are operated at a microwave frequency of 3 GHz in liquid helium at a temperature of 2 K. This operation temperature is well below $T_C = 9.25\text{K}$ of niobium and guarantees superconducting condition in routinely operation.

Occasional surface impurities, in particular after venting the beamline for maintenance work, can disturb the superconductivity and can lead to local break-downs of superconducting conditions. In such events it is desirable to have a method at ones disposal for locating and eliminating these surface impurities.

In order to locate quench sites on the superconducting cavities during operation in liquid helium a set-up using Oscillating Superleak Transducers (OSTs) was developed and tested in a vertical bath cryostat. For the experiments we used a cavity known to quench at very small accelerating fields. Despite the low rf power of approximately 4 W needed to quench the cavity, we were able to locate the quench sites with the OST set-up. Subsequent optical inspection clearly showed surface damages at the determined positions. We will report on our set-up and procedure.

S-DALINAC

At the S-DALINAC [1] (Layout in Fig. 1), the electron beam is provided either by a thermionic gun or an in 2011 implemented source for polarized electrons (S-DALINAC Polarized Injector - SPIN [2]). Both sources deliver their beam into the normalconducting injector beam line with a chopper/prebuncher system, which divides the continuous beam into bunches for the acceleration in the superconducting RF cavities.

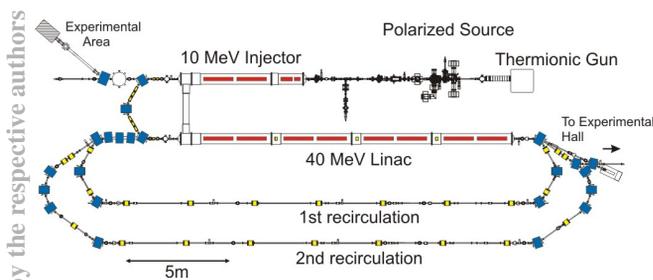


Figure 1: Floor plan of the S-DALINAC.

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Table 1: Designed and Achieved Figures of Merit of the S-DALINAC Cavities.

Figure of Merit	Design	Achieved
Frequency	2.997 GHz	
Length	1 m	
Quality factor Q_0	$3 \cdot 10^9$	$0.5 - 1 \cdot 10^9$
Accelerating field E_{acc}	5 MV/m	3 - 6 MV/m

In the superconducting part of the injector linac energies of up to 10 MeV can be achieved. Behind the injector the high-flux bremsstrahlung site DHIPS [3] uses this beam for nuclear resonance fluorescence and nuclear astrophysics measurements. Alternatively the beam can be bent by 180° into the main linac. This section consisting of eight superconducting 20-cell cavities is designed for an energy gain of 40 MeV and can be passed up to three times, due to the recirculating design of the S-DALINAC.

The beam can be extracted after each pass to the adjacent hall. There three different set-ups can be used for experiments: two for electron-scattering, the high-resolution 169° -(e,e')-spectrometer [4] and the high-acceptance-($e,e'x$)-spectrometer QCLAM [5], as well as a photon-tagger spectrometer NEPTUN [6].

BACKGROUND

For a couple of years quench localization arrays consisting of OSTs [7] are developed in most accelerator laboratories using elliptical superconducting cavities for electron acceleration.

For this work it was most important to prove that this technology of quench localization can also be applied for the low-field region of less than 5 MV/m, as the designed acceleration gradient of the S-DALINAC cavities is equal to that value. With a working frequency of nearly 3 GHz and 20 cells these cavities have an active length of 1 m. Fig. 2 shows a photograph of one of the S-DALINAC cavities while Tab. 1 gives the design values beside those achieved in operation.

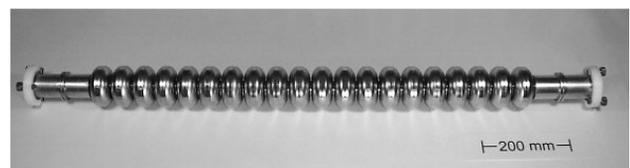


Figure 2: S-DALINAC 20-cell cavity.

OST DESIGN

Recent quench localization set-ups exploit the property of superfluid helium to transport introduced thermal energy as of a quenching cavity in the form of waves of second sound [8]. These waves propagate at velocities of approximately 20 m/s [9]. This is sufficiently slow for triangulation of the quench spot with small errors of some mm which allows for a proper identification of the quenching cell. In the phenomenon of second sound the superfluid component of the helium oscillates inversely phased to the normalfluid component. This is used by a special kind of capacitor microphone, so called Oscillating Superleak Transducers (OST), to detect the second sound. An OST as every capacitor microphone consists of two capacitor plates. One plate is vapor-deposited onto a very fine membrane filter (pore diameter $0.22 \mu\text{m}$) which can predominantly be penetrated only by the superfluid component of the second-sound waves. The other plate is solid. To ensure a high sensibility of the OSTs a design was developed, in which the aluminated membrane filter is put directly on top of a brass plate, forming the capacitor. Building the OST without an insulating coating of the solid capacitor plate could enlarge the capacitance by a factor of 4. To ensure electrical insulation of the plate, the casing of the OST was built of teflon. Fig. 3 shows the components of the Darmstadt OSTs and an assembled one.

Figure 3: Components of the Darmstadt OSTs. In the middle the two capacitor plates can be seen. On top an assembled OST is shown.

QUENCH LOCALIZATION ARRAY

The vertical bath cryostat in Darmstadt has a limited diameter of 35 cm and the OSTs have a limited angle of view as well. For that reason it was necessary to use 16 OSTs in four planes to cover the whole cavity. A photograph of the set-up is shown in Fig. 4. The OSTs are connected via coax-cables to a 22-pin-feedthrough on the top cover of the cryostat.

04 Measurement techniques

T. T-mapping and Second Sound

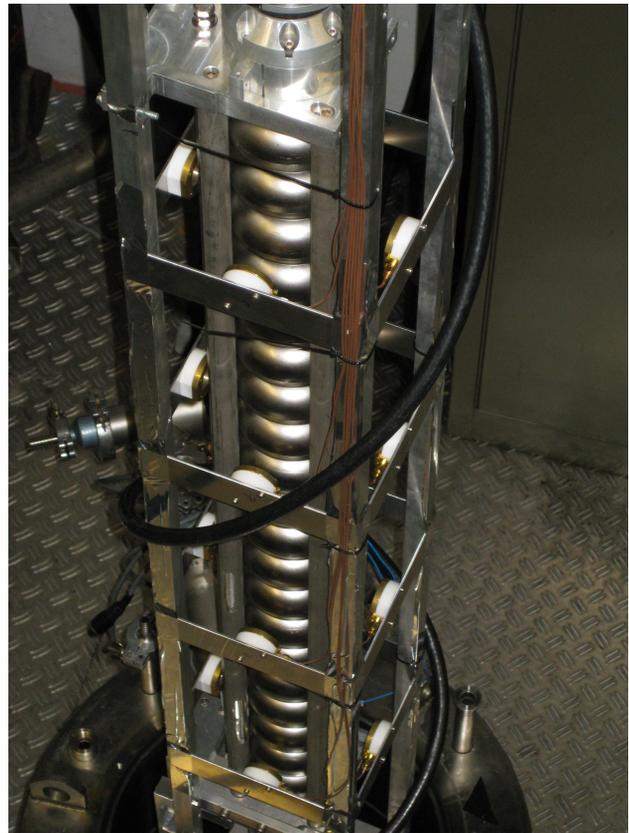


Figure 4: Darmstadt Quench Localization Set-Up. The OSTs are arranged around the cavity in four rings in order to cover the cavity completely giving the possibility of detecting quenches in every cell.

In addition to the OSTs, we developed a special amplifier board, which is designed to generate signals with very low noise from the OSTs. The board is equipped with a connector to fit on 22-pin-feedthroughs already mentioned. So it can be connected directly at the top cover of the cryostat and the low signals of the OSTs cannot be disturbed by ambient electrical noise, once the cables leave the electrical shielding of the cryostat. One of the boards is equipped with 8 amplifiers, so two boards are needed to read-out the full OST set-up simultaneously.

The amplified signals are digitized and analysed with a NI-ADC-PCI-Card and Labview. A typical graph of one of the OST-signals showing several quenches is shown in Fig. 5. The black curve gives the probe signal of the cavity, the red curve shows the signal of the OST. Both signals are measured simultaneously for 1 s. In the first 0.6 s the cavity is driven just below its quench limit, afterwards the input power is increased over the quench threshold. The cavity shows periodical quenching and re-filling with RF power. The OST detects increasing signals of second sound in this time-span. As the waves of second sound are reflected by the cryostat walls the signals of the OSTs do not decay to the noise level between two quenches of the cavity.

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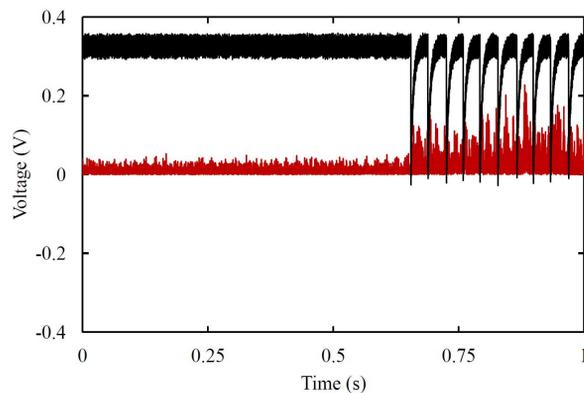


Figure 5: Typical graph of a series of quench events. The upper curve (black) shows the rf power coupled out of the cavity the lower curve (red) the detected OST signals.

FIRST RESULTS

The first cavity measured with the new set-up at the S-DALINAC has been out-of-duty for about 20 years. During that time it was stored vented and in ambient conditions. Prior to the test an ultra-sound cleaning was done but the assembly did not take place in clean room environment. So very low quality factor and quench limit were assumed. The cavity indeed quenched reproducibly at about 1.5 MV/m only in its 12th cell and the quality factor was calculated to be $3 \cdot 10^8$, only. An optical inspection carried out after warm-up and disassembly showed two considerable defects close to the iris of the quenching cell, shown in Fig 6.

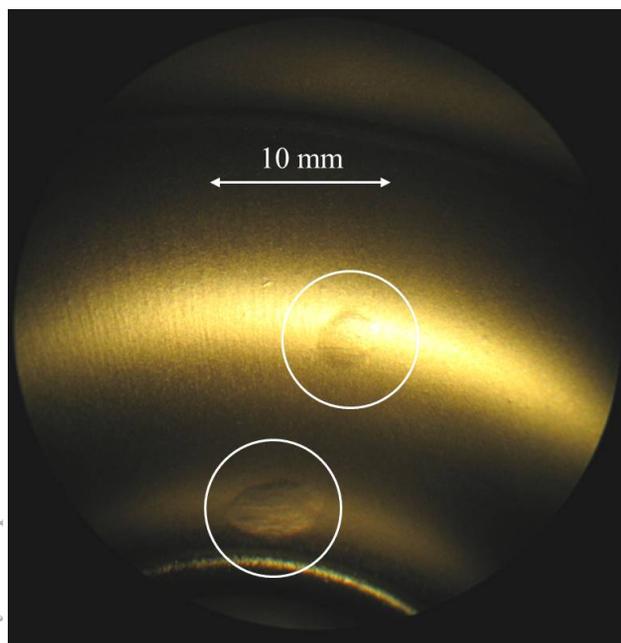


Figure 6: Defects close to the iris of cell #12, which has been identified to be the quenching cell using OST measurements.

OUTLOOK

With the first test of the Darmstadt OST Quench localization array the quench spot of an out-of-duty cavity, known to have a low quench field and a low quality factor, could be identified. After showing the usability of the set-up for cavities operated at low stored energies, it will be continuously used to scan conspicuous cavities of the S-DALINAC in the vertical bath cryostat. A planned modification of the frequency tuning system and the magnetic shielding of the S-DALINAC cavities in the accelerator provides the opportunity to implement the system inside the accelerator cryostats as well. So the S-DALINAC could become the first accelerator with an online quench localization system in future.

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