Progress in RF superconductivity at Saclay

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Abstract

The Saclay program of R&D on RF superconductivity is continuing, with applications in the frame of the TESLA and ELFE projects. The main topics under study have been the research of high accelerating gradients, and low RF dissipation in superconducting cavities. Thin superconducting films have also been investigated. We report substantial progress in these three areas.

1. HIGH GRADIENTS

The gradients available in superconducting cavities are now limited mainly by field emission. This phenomenon has been studied on samples, in both DC and RF regimes, with specific experimental set-ups. We have confirmed that micron sized dust particles substantially lower the threshold of field emission [1], and that dust contamination is one of the main reasons for field emission in RF cavities. Selective contamination experiments have shown that metallic particles behave as especially strong emitters. Greater care in cavity cleaning and mounting have in fact resulted in an improvement in cavity performance: accelerating gradients as high as 20 MV/m can now be reliably achieved in 1.3 and 1.5 GHz single cell cavities.

A large number of single cell cavities at 1.3 and 1.5 GHz made from RRR 180–250 Nb sheets have now been tested by our group. The most recent tests correspond to results significantly better than the previous ones. The improvement is thought to be due in part to the use of a locally developed automated facility for chemical polishing, rinsing and drying [2], and to improved mounting techniques.

Three-cell cavities have also been tested in vertical cryostat before installation in the prototype accelerator MACSE. The average accelerating gradient obtained by these four cavities was 18 MV/m, and was limited by quenches.

We observe a gradient limitation at 18–23 MV/m in all cavities. This limitation seems to be intrinsic, since the majority of the tested cavities reached the maximum gradient without field emission.

Gradients as high as 29 MV/m have been reached with cavities fired and titanified in a vacuum furnace (typically 1300°C during 16 hours) (fig. 1). It is interesting to note that very good results were also obtained by firing half cells before electron beam welding of the cavity. Altogether, firing seems to be indispensable if very high gradients are required.

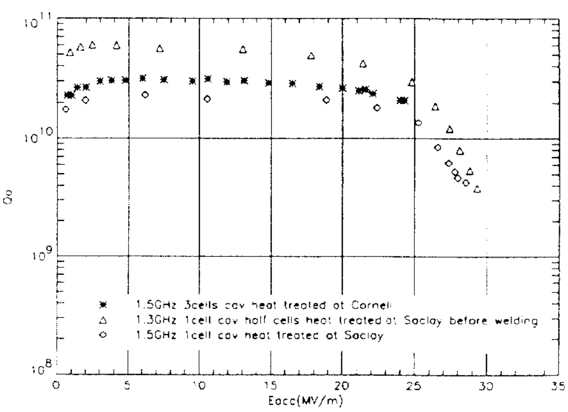

Figure 1 Q value vs accelerating gradient for three heat treated "high gradient" cavities

A high peak power processing facility is in preparation in our laboratory. The 1.3 GHz klystron will provide RF peak power pulses up to 1 MW during 1 ms at a repetition rate of 0.1 Hz. The klystron power supply and the cryostat insert are now being assembled. The first RF power tests on the variable input coupler will start in August.

2. LOW DISSIPATION

The residual surface resistance R_{res} routinely obtained with our Nb cavities is 15 nΩ at 1.5 GHz. A special effort has been undertaken to understand and to minimize the causes of this residual dissipation. The contribution to R_{res} due to trapped flux has been revisited theoretically and experimentally [3]. With the anterior level of magnetic shielding in the Saclay vertical test cryostats, this contribution amounted to 5–10 nΩ, i.e. a non negligible fraction of the total R_{res}. Suppression of this dissipation was achieved thanks to improved magnetic shielding, giving a residual magnetic field of 2 mG. Q values of 5–7 10^{10}, corresponding to a residual surface resistance of 3–6 nΩ, are now reached reproducibly with single cell niobium accelerating cavities at 1.3 and 1.5 GHz (Fig 2). To obtain this result, special care was also taken in the cavity design to avoid RF losses at the ends of the cutoff tubes. The use of high purity niobium (RRR 280) may also have played a favorable role. By showing that the residual dissipation in well treated, well designed cavities can be very small, this result considerably clarifies the list of other possible causes of residual dissipation. We shall try to determine how its validity can be extended to a cavity in a real accelerator environment.

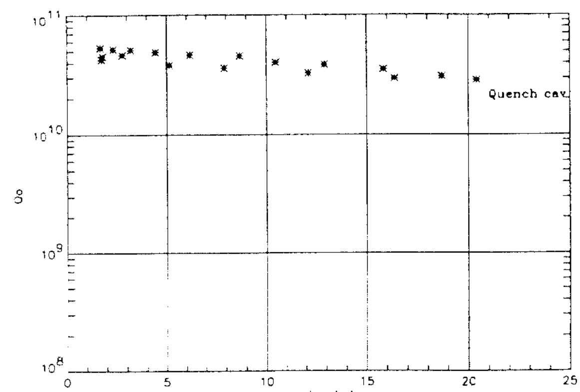

Figure 2 Q value vs accelerating gradient for a "low dissipation" cavity

3. THIN SUPERCONDUCTING FILMS

Efforts have also been continued to develop the thin film coating technology at Saclay [4,5]. Several samples of NbTiN film, deposited on 12 cm copper disks by magnetron sputtering and tested in a cylindrical TE011 cavity, reached RF field levels of 35 mT and exhibited a low residual surface resistance (< 100 nΩ at 4 GHz) with a very small BCS resistance (fig. 3). We are presently adjusting the sputtering parameters in order to deposit NbTiN films with good adherence in 1.5 GHz copper accelerating cavities.

A collaboration with CERN has also given interesting results, since single and 5–cell Nb/Cu 1.5 GHz accelerating cavities, sputtered at Saclay and assembled and measured at CERN reached Q values as high as 1.5 10^{10} and accelerating gradients of 16 MV/m [6].

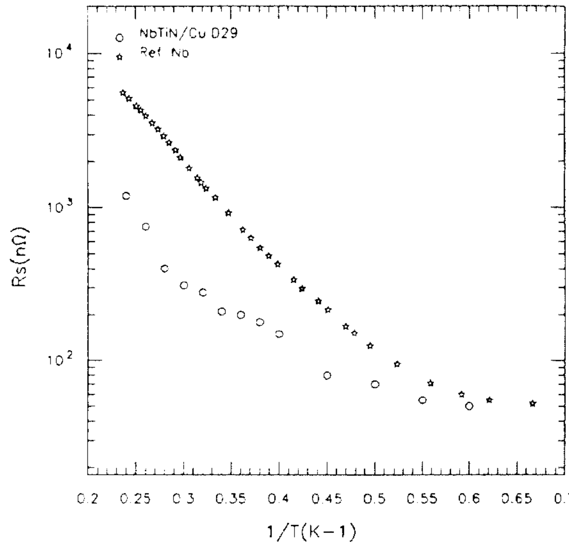

Figure 3 Surface resistance vs temperature for a NbTiN sample, at 4 GHz.

4. PROGRESS ON THE ACCELERATOR MACSE

The MACSE prototype [7] has been operated in several runs for testing 5–cell cavities performance, cryogenic installation and beam characteristics. During the past three years, operation of the accelerator was always found to be very stable and reliable. No degradation of cavity performance was observed after long periods of shutdown at room temperature. In one case, a cavity was left during 6 months under static vacuum and recovered its previous characteristics after a short RF processing.

One-by-one cavity tests showed that pulsed RF processing at moderate power (5 kW) suppressed or at least reduced electron loading due to field emission. The accelerating gradients, limited by quench, reached an average value of 12 MV/m. A gradient as high as 18 MV/m has been measured in one cavity, limited only by input coupler breakdown.

The powering of 3 cavities with only one klystron and a vector sum regulation loop has been successfully tested with little energy spread degradation.

Many beam tests have been performed and are reported in [8]

5. RF MEASUREMENTS FOR THE TESLA TEST FACILITY

Saclay has taken an active part in the TESLA collaboration. Among other contributions, RF tests of the first TESLA 9–cell cavity (#-2) have been performed in a vertical cryostat at Saclay. Heavy electron loading limited the accelerating gradient to 6 MV/m.

RF tests on HOM coupler prototypes for TESLA have also been performed. Two designs, not directly cooled by liquid helium: DESY (welded coupler [9]) and Saclay (demountable [10]), have been tested in a 1.5 GHz single cell cavity. In order to qualify the demountable coupler, tests were made in CW mode (fig. 4) and in pulsed mode with a detuned filter. Satisfactory results were obtained, since an accelerating gradient of 20 MV/m, limited by a cavity quench, was obtained in CW mode, and a peak power of 1.75 KW was sustained during 0.8 ms in pulsed mode.

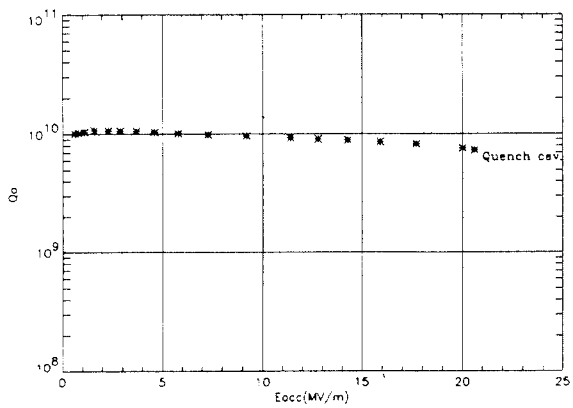

Figure 4 Q value vs accelerating gradient for a cavity equipped with a demountable HOM coupler

6. REFERENCES

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