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Progress in RF superconductivity at Saclay

B. Bonin, for the DAPNIA-SEA*, CE Saclay, F–91191 Gif/Yvette, France
and Institut de Physique Nucléaire** Université de Paris Sud, F-91400 Orsay, France

ABSTRACT

The Saclay program of R&D on RF superconductivity is continuing, with applications in the frame of the TESLA and ELFE projects. The activities range from beam production with the Saclay heavy ion linac, to basic studies on superconducting cavities. Between these two extremes, the prototype electron linac MACSE has been put successfully into operation. The most important issues and results of this research will be shortly described here.

I. BASIC R&D ON RF SUPERCONDUCTIVITY

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.

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 1.5 GHz single cell cavities (Fig.1).

A large number of single cell Nb cavities at 1.5 GHz have now been tested by our group. The corresponding systematics are summarized in Fig.1. It can be seen that 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.

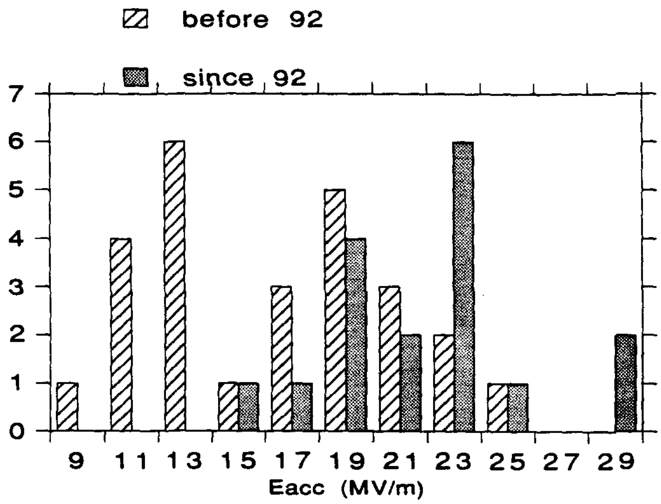

Figure 1 Maximum accelerating gradient for the Saclay single-cell Nb cavities at 1.5 GHz.

In the above statistics, all cavities were made from RRR 180–250 Nb sheet. The gradient limitation in these cavities seems to be intrinsic, since the majority of the tested cavities reached 18–23 MV/m without field emission. None of them underwent a heat treatment. Only the two tests with the highest gradient of 28 MV/m (Fig. 2) were made with cavities fired and titanified at 1300 °C during 16 hours in a vacuum furnace. Firing thus seems to be indispensable if very high gradients are required.

A high peak power processing facility (1 MW at 1.3 GHz) is also in preparation in our laboratory.

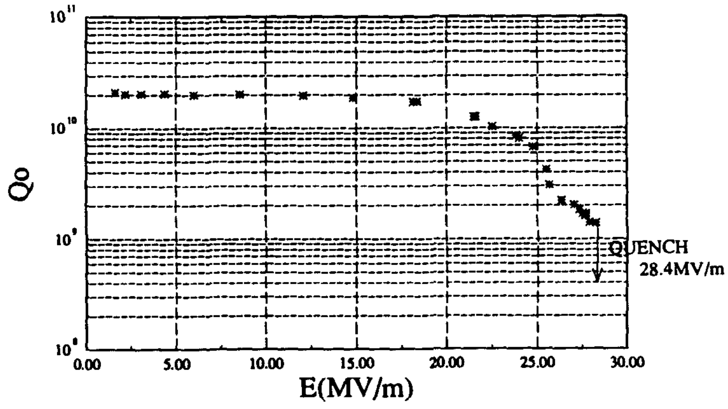

Figure 2 Q value vs accelerating gradient for a "high gradient" cavity

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 1.5 GHz (Fig 3). 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.

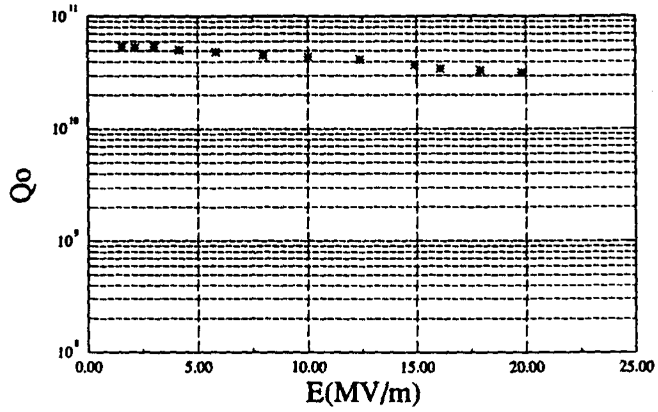

Figure 3 Q value vs accelerating gradient for a "low dissipation" cavity

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 copper substrates by magnetron sputtering, 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 and an unusually small dependence of Rs vs RF field. So far, 12 cm disk samples have been tested in a cylindrical TE011 cavity. In view of the present results, complete accelerating cavities will be made in the near future.

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].

II. 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 installed cryogenic power is about 100 W but, due to static losses, the power available to run with the capture and the four accelerating superconducting cavities is about 60 W. For this reason, and also because of excessive losses in one input coupler cold window and in one electron emissive cavity, the energy of the beam was limited to 13.2 MeV (1.9 MeV after the capture cavity).

A continuous electron beam of 100 μA has been accelerated with excellent stability, emittance and energy spread ($\Delta E = 7$ keV). The powering of 3 cavities with only one klystron and a vector sum regulation loop has been successfully tested with little energy spread degradation.

Future tests with 3–cell cavities

A new generation of cavities and couplers will be installed and tested in MACSE before next fall. Thanks to a higher value for the ratio E_{peak}/E_{acc}, these 3–cell cavities should reach higher gradients than the previous 5–cell ones. The average accelerating field obtained by the four cavities in vertical cryostat was 18 MV/m. The cavities will be equipped with loop-type HOM couplers with inner conductor cooling [8]. These couplers have demonstrated the capability of withstanding accelerating gradients of 15 MV/m in vertical cryostat.

III. PARTICIPATION IN THE TESLA COLLABORATION

Saclay has taken an active part in the TESLA collaboration, particularly on the following items:

—Participation in the design of the 9–cell cavities;

—Design and fabrication of the cold tuning system;

—Design, test and fabrication of HOM couplers;

—Design and fabrication of the horizontal cryostat CHECHIA. This set-up will permit the test of fully equipped cavities, in an accelerator-like configuration;

—Realization of the low charge injector for the TESLA Test Facility, in a joint effort with two other french institutes: IPN and LAL, Orsay. The injector capture section features a 9–cell superconducting cavity housed in a separate cryostat.;

—RF studies concerning field and phase stabilization in pulsed mode;

—Beam dynamics studies for the TESLA 500 accelerator;

—Basic R&D on RF superconductivity, oriented towards obtaining cavities with high gradients and low RF dissipation.

IV. THE SACLAY HEAVY ION LINAC

The Saclay heavy ion superconducting linac has been in operation since mid 1989. A detailed account of the accelerator performance can be found elsewhere in these proceedings [9].

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** M. Caruette, M. Fouaidy, T. Junquera