A new surface treatment for niobium superconducting cavities

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Abstract

A condition necessary for the successful performance of superconducting cavities is the cleanliness of their inner surface. The firing of niobium cavities under vacuum at very high temperature is known to be a particularly effective method for cleaning the surface and for suppressing electron field emission. However, this process is inconvenient and expensive, if it is done in the "usual way", ie in a high vacuum furnace. We propose an alternative technique for cavity firing, using local heating in an electron beam or laser welding facility. This treatment is easy, and can readily be integrated in the usual process of cavity production. Initial tests at Saclay have given very promising results.

I. INTRODUCTION

The cleanliness of the inner surface of superconducting cavities is an indispensable condition for the successful performance of these accelerating structures. The firing of niobium cavities under vacuum at very high temperature is in wide favor in many laboratories for at least two reasons : i) when used in association with solid state gettering (e.g. titanification or yttrification [1]), it permits a purification and a homogenization of the material, with a subsequent improvement of its thermal conductivity, and a better stabilization of the cavity against quenches; ii) this treatment seems to inhibit the activity of the microscopic sites where electron field emission takes place. The field emission threshold which limits the accelerating gradient available in the cavity is then pushed to higher levels.

However, firing is usually done in a high vacuum furnace, which makes the process inconvenient and expensive. There is also a very serious risk of recontamination of the cavity surface during the furnace venting, since the cavity is necessarily open during treatment. The benefits of the bulk purification of the material are then kept, but the protection of the cavity against field emission may be lost after the treatment. Firing of niobium cavities in a high vacuum furnace is thus difficult to integrate in an industrial process of cavity production.

We have explored an alternative technique, which employs local heating in an electron beam welding facility. The interst of the method lies mainly in its simplicity and its rapidity. The local character of the heating may also present some advantages : for instance, the cavity flanges can be spared during the treatment. This alleviates the need for refractory flanges, and opens up the interesting possibility of firing *closed* cavities.

II. EXPERIMENT

All the firing experiments were done in the EB welding machine of LMS, at Saclay. Its TECHMETA electron gun delivers an electron beam of controllable energy, intensity and focusing. The electron beam pencil can be moved and vibrated across the sample surface by means of suitable deflecting electrodes. The vacuum in the vessel is no better than 10^{-3} Pa.

The first firing tests were made on 2mm thick niobium sheet samples. The sample temperature during firing was measured by means of a bichromatic optical pyrometer viewing the sample through a window in the EB welding machine. The accuracy of the measurement was on the order of ± 100°.

In all practical cases, the electron beam dwell time on one given point of the surface was long as compared to the characteristic time of heat diffusion across the niobium sheet. For this reason, we believe that the temperature was identical on both sides of the sheet.

The first tests showed that any chosen temperature between 1000° and 2000° C could be reached and maintained with excellent stability, by a suitable choice of the following parameters : electron energy, beam size, beam intensity and displacement speed.

The fired samples showed a considerable recrystallization: starting from an initial grain size of 50–70 μm, the final grain size was as large as 1 cm for the hottest and longest runs. The initial purity of the Nb samples was RRR=200. No degradation of RRR was observed for the shortest runs (15 sec), but a significant loss of purity (RRR=50) resulted from the long firings (15 min), even at very high temperature. This is attributable to the fact that residual gaseous species present in the vacuum enter readily as interstitials in the niobium lattice at high temperature [2,3]. The important degradation observed can then be ascribed to the poor vacuum in the welding machine.

These considerations led us to protect the niobium before and during firing, by means of a titanium vapor layer deposited on the sample surface by sublimation of a joule—heated titanium filament. Contamination from the residual gases is then confined to the outside titanium layer, and no longer affects the bulk niobium. New RRR measurements after this treatment showed no purity degradation, thus confirming the success of this protection method. In the present experiment, the Ti layer could be deposited only on one side of the Nb sheet sample. In this case, there is probably competition between a pollution of the material from the unprotected side, and a purification from the titanified one. A real purification of the bulk material

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could be expected from a more careful titanification, covering both sides of the sample.

As compared to the titanification in general use for the firing of niobium cavities in high vacuum furnaces [1], the above-mentioned method has the advantage that the Ti filament and the niobium sample to be treated are heated separately to (eventually) different temperatures. This gives an appreciable control of the sublimation rate and of the thickness of the Ti layer on the sample surface during firing. This nice feature, which allows the deposition of the titanium layer *before* the firing, should improve the efficiency of the titanification by suppressing the risk of pollution during the passage through the dangerous temperature zone where the niobium is already hot enough for the impurities to enter, and is still unprotected by the titanium sublimation.

In order to assess the validity of the technique for the practical treatment of superconducting cavities, a single cell, 1.5 GHz niobium cavity was heated in the EB machine, with the following particular features :

1) The cavity was mounted on a horizontal mandrel and rotated in front of the fixed electron beam ;

2) The cavity was titanified from outside by sublimation of a joule-heated titanium filament parallel to the cavity axis ;

3) The cavity -already equipped with its antennas- had been sealed under static vacuum before firing. The motivation for this sealing was to protect the cavity against pollution by the (poor) residual vacuum during firing, and against any ulterior contamination by dust particles or by chemical species after firing. The cavity was not reopened after the treatment, and was directly tested in a vertical cryostat, still under the same static vacuum ;

4) All points of the cavity surface were maintained at 1850° C during 1 minute. After the heat treatment, the cavity surface showed the same considerable recrystallization as was observed on sheet samples. No noticeable deformation of the cavity shape could be detected.

This cavity showed excellent RF performance, giving an accelerating gradient of 19 MV/m and a residual Q value above 10^{10} without any electron emission. Although we consider this result very encouraging, it must be noted that this gradient and Q value had previously been obtained with this same cavity after a standard chemical treatment and mounting. Hence, we cannot claim an improvement of the cavity performance due to the heat treatment.

Clearly, the curative virtues of the treatment are still to be demonstrated, but there is some hope that this kind of firing might replace the delicate chemical etching, rinsing and clean-room drying that represent the "state of the art" for superconducting accelerating cavities.

VI. CONCLUSION

We have shown that an electron beam heat treatment of niobium superconducting cavities is an interesting possibility, probably superior to the usual high vacuum furnace heat treatment. Suitable electron beams are already available in industry in EB welding machines, whereas high vacuum furnaces are still laboratory objects. The poor vacuum of our EB welder obliged us to contrive complicated arrangements to avoid the pollution of the niobium by residual gases. However, EB welding facilities with improved vacuum (10^{-5} Pa) are available. In such devices, a high vacuum level during treatment would certainly be easier to achieve than in furnaces, because there are no screens and because the only hot surface is the desired one. The potential cleanliness of this kind of heat treatment is thus excellent. The local heating of the surface opens rich perspectives, which have not yet been explored. Experiments are under way at Saclay to determine the benefits that can be obtained from such a treatment, from the points of view of curing field emission and purifying niobium. The parameters of the treatment (temperature, duration) remain to be determined.

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VII. REFERENCES

[1] H. Padamsee et al., IEEE T. Mag 21 1007 (1985)
[2] M. Hörmann, J. Less Comm. Metals 139 1 (1988)
[3] K.K. Schulze, J. Metals, May 1981 p.33