Acceptance Tests of Superconducting Cavities and Modules for LEP from Industry

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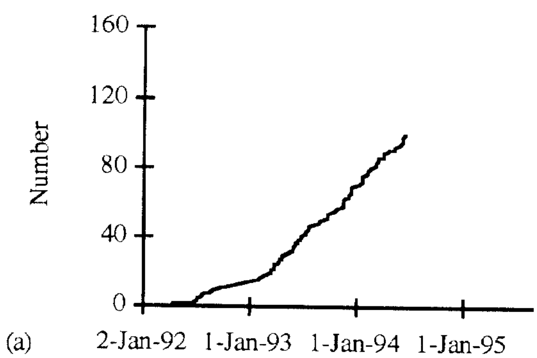
Abstract

One hundred superconducting RF cavities have been produced and accepted for the energy upgrade of LEP (LEP2). The specified Q-value is $4 \cdot 10^9$ (4.2 K) at the accelerating gradient of 6 MV/m. A statistical analysis of the cavity performance data and experience encountered along the mass production are presented. After assembly of the individual cavities into cryo-modules of four, and mounting of power and higher mode couplers, unforeseen problems on these auxiliary elements have hampered the installation into LEP.

1. INTRODUCTION



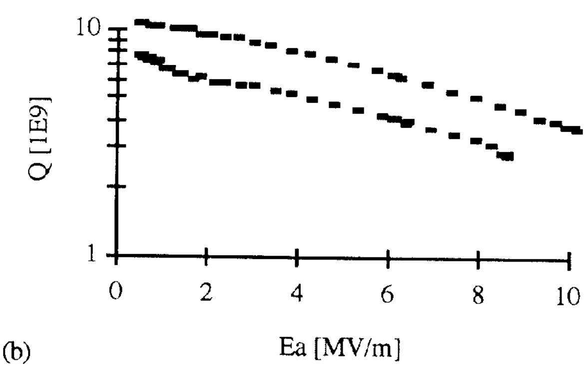


Fig. 1. a) Total number of accepted cavities (vertical test) vs. time for the series production of 168 NbCu cavities.
b) Q-value at 4.2 K vs. accelerating gradient for two cavities from one company with the best and (contractually tolerated) worst performance. Cavities from the other companies behave similarly. The lower curve has originally been measured at 4.5 K, but for comparison, the data were extrapolated to 4.2 K.

The centre of mass energy of the electron positron collider LEP is going to be increased from the actual one around the Z_0 boson mass of 91 GeV to about 170 GeV above the W^+W^- pair production threshold. For this upgrade 192 superconducting cavities will be needed, the major part of which being of the niobium sputter coated copper (NbCu) cavity type. We will report on the status of the industrial fabrication of the individual four-cell cavities and the modules (composed of four individual cavities). A previous status report is found elsewhere [1].

2. INDUSTRIAL PRODUCTION

2.1 Individual cavities

Three orders for about 50 LEP cavities each were placed with three different European companies (ANSALDO, CERCA and SIEMENS) at the end of 1990. The series production is well underway and 100 cavities have been accepted (after the test in a vertical cryostat). The accumulated number of accepted cavities and the typical performance are shown in Fig. 1.

The technical know-how successfully transferred to industry, a continuous acceptance rate was achieved. However, two main problems were encountered in the production process.

The first was related to the presence of a large number of defects, detected in the Nb film [1]. The origin of these defects was attributed to the presence on the copper sheets of a layer (about 100 μm thick) damaged by the rolling operations. This problem was solved by increasing the thickness of the copper surface layer removed by electropolishing and chemical etching from 80 μm to 140 μm. The shiny surface obtained was an advantage to locate defects and to remove them mechanically.

The second problem encountered was a high rejection rate for cavities coated for the first time, whereas the second coating generally was successful (Fig. 2). Analyses are under way at CERN, in collaboration with industry, looking more carefully at the temperature for baking and coating, which is believed to be the critical parameter for this phenomenon.

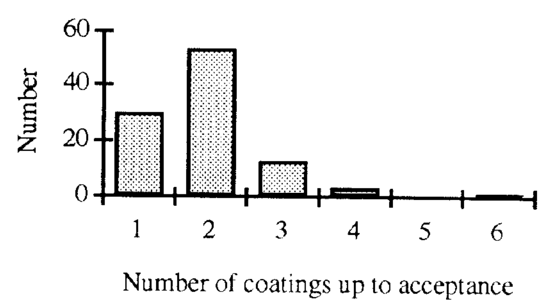


Fig. 2: Number of cavities having been submitted to a first and further coating before acceptance.

The data collected on the residual Q-value (the Q-value at the lowest gradient and at the lowest temperature) clearly demonstrate the dichotomy of the first and second coating, too (Fig. 3).

The rejection rate for cavities having undergone the first coating was particularly large for two companies, and still tolerable for the third one. If a cavity had to be coated a second time, the results from the different companies were quite similar. The parameters applied for the fabrication process were thoroughly cross checked between those two companies and the third one. No obvious discrepancy was found except the layout of a heater box used for bakeout and coating. Whereas in company 3 this device left plenty of space for the ambient air to cool the cavity by natural convection, companies 1 and 2 used a closed cylindrical box for homogenising the temperature inside. The cavities which left the coating set-up had were covered with dark copper oxide, whereas those produced by company 3 were bright and reddish typical of copper.

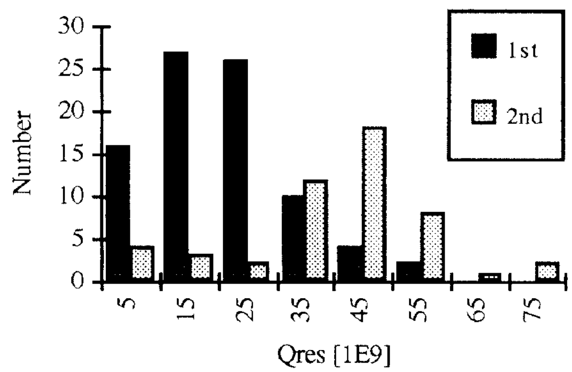


Fig. 3: Residual Q-value for first and second coating.

This observation led to the idea, that the temperature during bakeout and/or coating is one key parameter.

Therefore, at these two companies, this box was no longer used. During bakeout the temperature decreased from 200°C to less than 150°C and during coating from 220°C maximum to about 180°C. The success rate for the first coating sprang up from 15% to more than 60 % (5 out of 8 successful). This has to be compared with the alternative to test the cavity only after having been submitted to two coatings (with a removal of the first one in between). Then the success rate was 90 % (7 out of 8 successful) for the second coating (in this case the cavity was coated once, the first coating removed, and the cavity was coated for the second time).

Since the heater box is no longer in use, the RF results of the cavities from the three different companies are very similar also for the first coating.

2.2 The cryo-modules

The majority of the 100 accepted cavities have been assembled into cryo-modules. So far 19 out of the 42 ordered ones have been delivered to CERN; 18 of them have been tested and 12 have reached the required performance levels, which are a Q-value not lower than $3.2 \cdot 10^9$ at 6 MV/m and 4.5 K.

Out of these modules 13 have been equipped with power and higher order mode (HOM) couplers but due to the recent problems with HOM coupler quenches [2] - partly hindering processing - the last modules have been delivered and tested without HOM and power couplers. The missing couplers are to be fitted once the coupler problems will be solved.

Leaving out the first module, which was contaminated by a vacuum accident during transport to CERN, out of the other 68 cavities in these modules only 9 (13%) had to be refused in this initial phase. 11 modules could be accepted in the first test, 5 modules had one and 2 had two cavities below specifications. Two modules including the very first one have meanwhile been recovered, using ultra-pure water rinsing of the poorly performing cavities. This shows that modules can be recovered without a second coating.

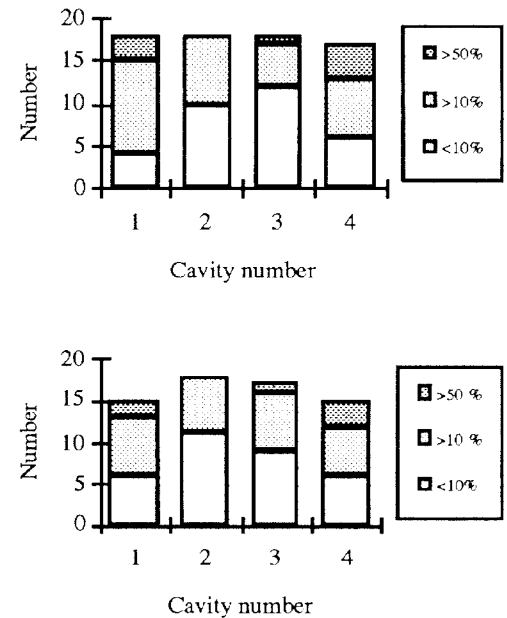


Fig. 4: Histogramm of number of cavities having undergone a degradation after assembly. The relative change (in %) of RF loss between the vertical test and the horizontal test is shown. The upper plot refers to the RF loss at low field, the lower plot to the RF loss at 6 MV/m. Numbers below 10% are insignificant. Cavity numbers 1 and 4 are located at the end of the cryo-modules, 2 and 3 are located in the middle. The degradation is larger in the end cavities.

The Q-values at low and high gradient (vertical test) were correlated to the ones (horizontal test) measured immediately after assembly into a cryo-module (Fig. 4). There are hints of a stronger contamination in the end cavities of a module compared to the middle ones, the source of which is not understood.

3. DISCUSSION

We have found indications for the following points, which actually are being thoroughly investigated.

1) The temperature is a key parameter for the coating process. If it is too high, contaminants may degrade the coating.
2) These contaminants must originate from a "reservoir", which is continuously depleted from one coating to the next.
3) Actions as removing the first niobium layer, chemical polishing, bakeout or a second coating do not "refill" this reservoir.

As source of contamination, the bulk copper material was taken into consideration. The niobium layer may act as a getter, which depletes the copper from impurities, depending on the temperature. These impurities may influence the granularity of the film, known to affect its RF performance (cf. companion paper to this conference [3], [4] and references therein).

4. CONCLUSION

A smooth reception rate of 5 cavities per month of NbCu cavities from industry could be obtained and 100 out of 168 individual cavities are accepted. The temperature during bakeout and/or coating is a key parameter. After assembly into cryo-modules, the end cavities show signs of contamination of unknown origin. Nevertheless, 12 cryo-modules out of 42 ordered ones have been accepted so far.

ACKNOWLEDGEMENT

We like to thank our colleagues R. Hanni, E. Magnani, and A. Scharding for the vital part they take in assuring the contact with the three firms, and A. Insomby and H. Preis for assembly and vacuum generation. We thank the Thomson crew, who is doing the RF tests in a competent way, and F. Haug and the cryogenic crew for supplying the quantities of liquid helium needed.

We also appreciate the aid and the close collaboration with C. Benvenuti and his group, who help us to understand the physics of the coating.

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