Some Results about RRR Distribution in Nb of Superconducting Cavities for TESLA Test Facility

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Introduction

The RRR value indicates the purity of niobium. Generally the maximal surface magnetic field of a cavity is proportional to square root of RRR. However, the correlation between cavity performance and cavity's RRR is not always so obvious, especially for material with RRR greater than 300[1]. The reason may be the material inhomogeneity [2].

Two kinds of RRR test systems are applied for the TESLA Test Facility[3] at DESY: a conventional 4 point measurement system[4] and a novel eddy current test system[5]. The 4 point method, as a kind of an absolute measurement method, is more accurate than the eddy current method. But compared to eddy-current method, it has the following disadvantages:

1. It is kind of a destructive method. It cannot be used for real cavity's RRR test, although the cavity's RRR values should be available after each processing procedure. For this purpose the eddy current can be recommended as a quite appropriate non-destructive method.

2. It is not a local measurement method. It can be used only for a sample about 80 mm long. The sample's RRR value is an average value of the whole piece, while the eddy current method can be used for measuring RRR within quite a small area (with a diameter about 5 mm) and with a penetration depth, which can be set up between 100 µm and 1 mm.

In order to learn about the homogeneity of niobium material, a series of RRR measurements has been done. We present some examples of RRR distribution in a nine-cell cavity, of the RRR distribution of a half-cell cavity and of the RRR distribution in the cross-section of the as delivered and post purified Nb material. The cavity RRR test system is also presented.

TTF Cavity RRR Test System

On the basis of the eddy current RRR test system for samples, an improved cavity RRR test system was created.

The system includes a function generator, eddy current probes connected to each other as induction bridge, a multichannel scanner, a lock-in amplifier, a digital voltmeter, GPIB interface and a Macintosh PC. The measurement principle is: the function generator establishes a 213 Hz/150 mA current in the primary coil of the probe. The related penetration depth in Nb is about 1 mm at Tc before the superconducting jump. The primary coil induces an eddy current in the Nb wall of the cavity. The eddy current magnitude, as a function of material's impedance, is measured by a pickup coil, which touches the cavity surface. Two signals U_s and U_n are acquired during the cavity cooling down (or warming up) are used for RRR estimation. U_s is the pickup signal in superconducting state at Tc, while U_n is the pickup signal when cavity is still in normal conducting state at Tc. With the help of the beforehand determined calibration curve RRR=f(U_j/Us), the RRR is evaluated ($U_j=U_s-U_n$ - the superconducting jump). U_s defines reference value, that allows to reduce the error caused by the variation of the distance between the probe and the cavity wall. The program was written by Labview 3.1.1. It includes a zero point correction function. At room temperature, the signals of each probe are collected as zero points, so that they can be subtracted during measurement.

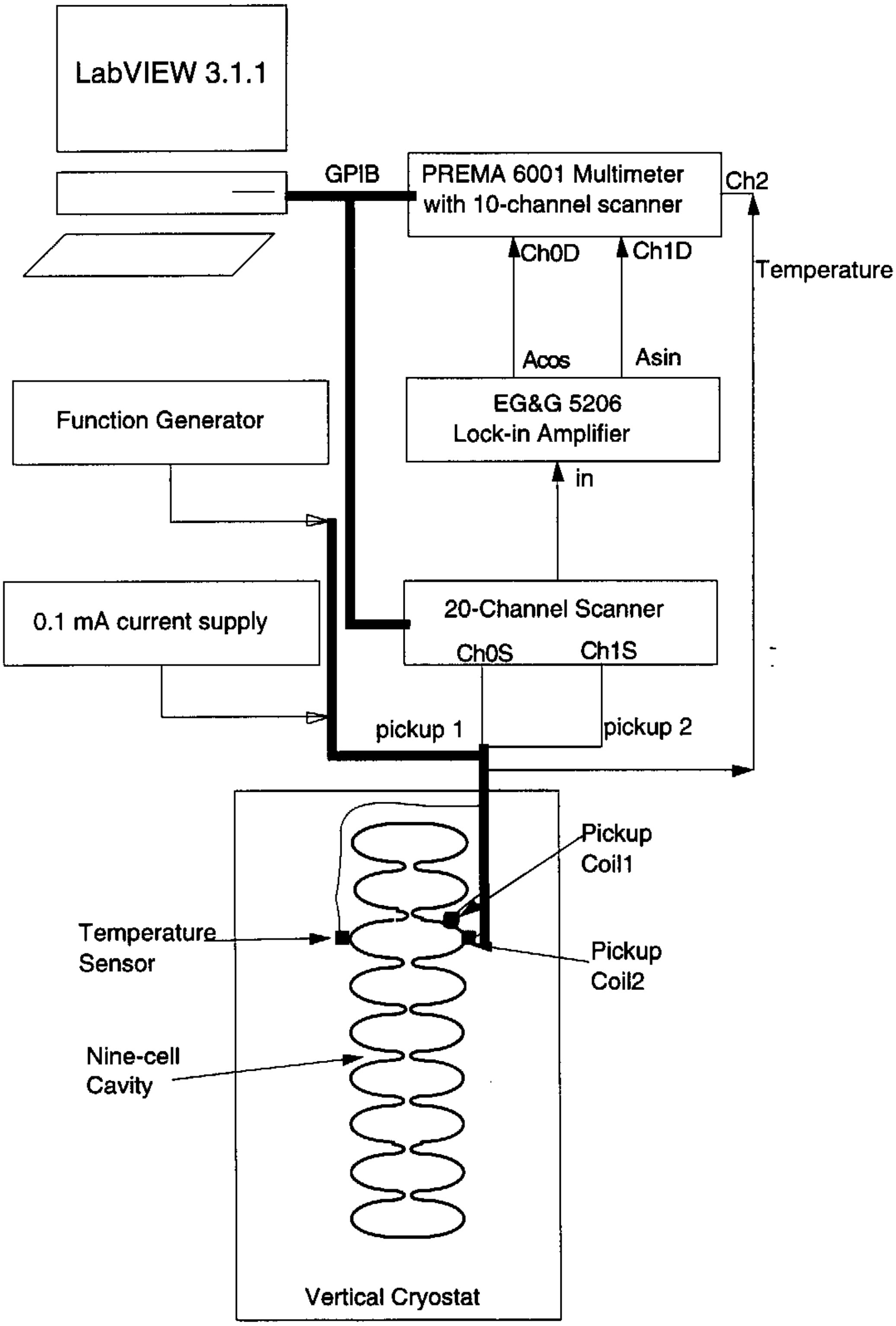

Fig.1 A two pickup coils cavity RRR test system

The RRR Distribution on a Nine-Cell Cavity

With the eddy current RRR test system, the uniformity of RRR from cell to cell and from welding to welding in some TTF cavities is investigated. For example, for the cavity C21 RRR values on different cells are summarized in Fig.2. The probe location above and below welding was about 15 mm away from the equator.

The RRR values on EB welding are somewhat lower than those away from the welding. The same behavior was found on samples earlier[6]. The cavity C21 was built at CERCA from Nb sheets produced by Wah Chang. The RRR in samples was between 350 and 450. We can see that the RRR values are smaller in the cavity, which is evidently caused by deep drawing. On the other hand the RRR of different cells are rather close to each other (between 420 and 340). That means the RRR difference from sheet to sheet was probably not very big.

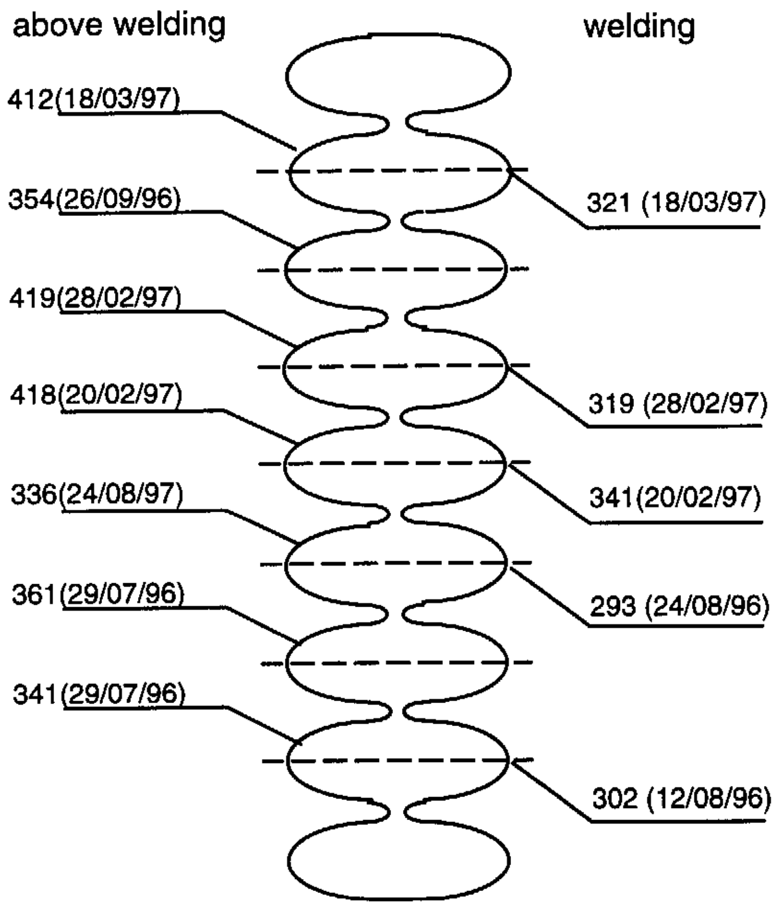

Fig. 2 Cavity C21 RRR test results

TIG Welding

Some repair welding by TIG has been done at the pick up probe located at the beam pip. There is practically no fundamental mode current, so that the deterioration RRR is of no consequence. It is of importance, however, whether the zone of degradation RRR extents to the neighboring cavity cell.
Therefore we checked the quality of TIG welding and the influence on RRR next to the welding, some experiments were done. As shown in Fig.3, the RRR values on TIG welding place are much lower than those on other places. But it is quite local. The RRR is not degraded in a distance of 40 mm from the welding. Compared to Electronic

Beam welding, which doesn't cause much change on RRR, TIG welding is not acceptable for cavity production.

Cavity C22 RRR

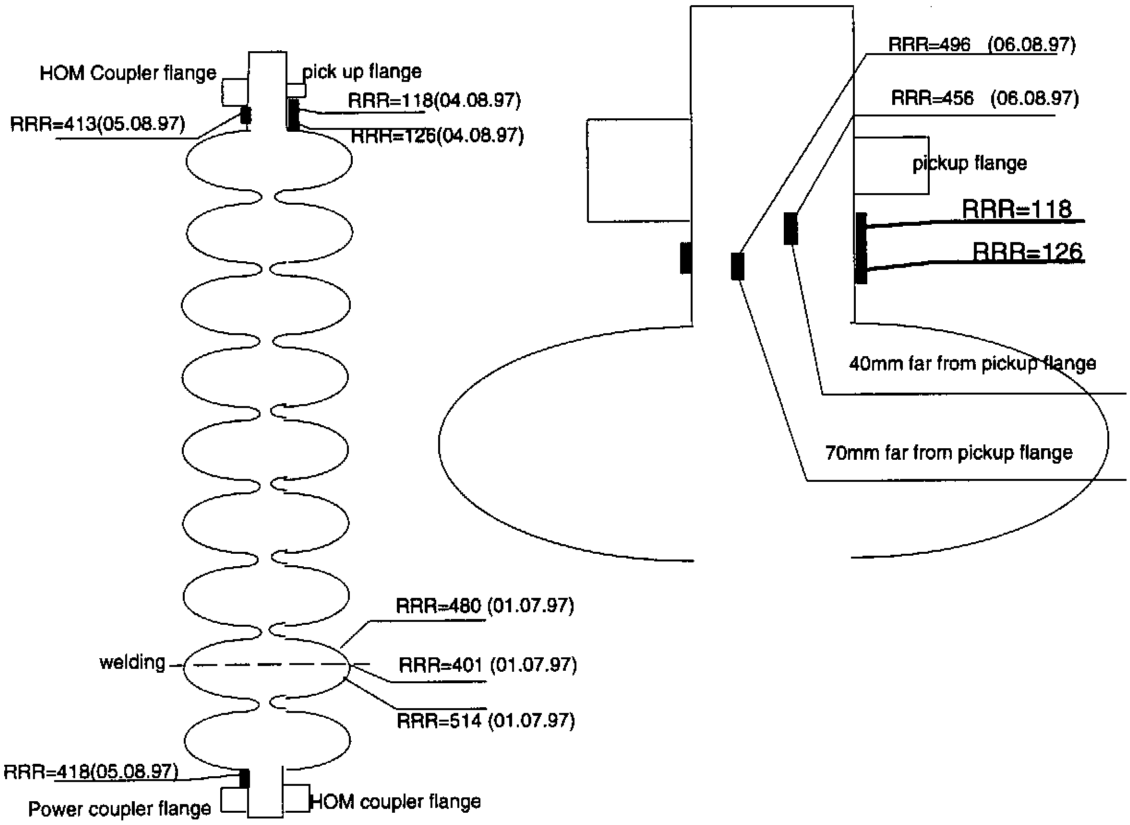

Fig.3 TIG welding test results

Some TIG welded samples have also been measured by the eddy current method. Fig.4 gives the RRR distribution on the area near to the welding. It is quite clear, that TIG welding causes RRR degradation next to the welding.

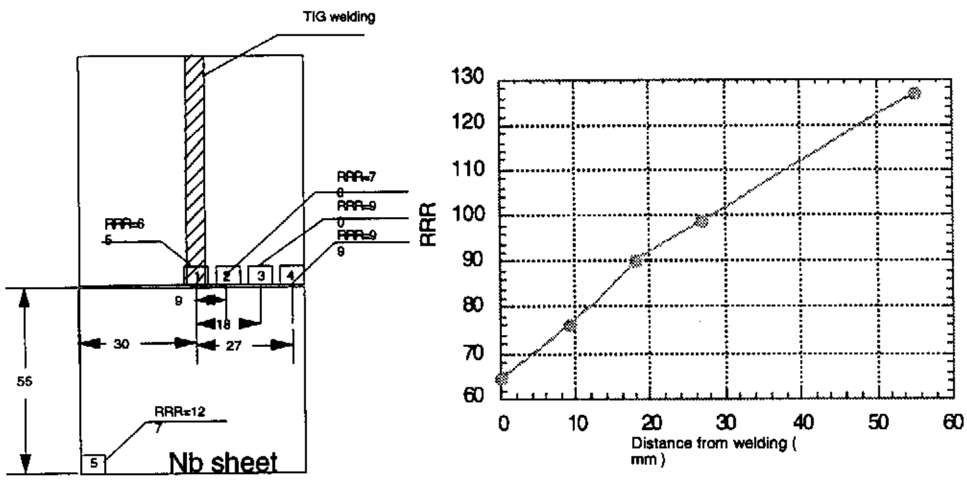

Fig.4 TIG welding sample RRR distribution

RRR Distribution within a Half-Cell of the Cavity

Eight samples (9x9x2,8 mm) were cut out for eddy current test (see Fig.5) in order to investigate the homogeneity of RRR distribution in a half cell after deep drawing. Fig.6 presents the RRR results. It can be seen, that the RRR degradation caused by the deep drawing is not significant (initial RRR≈270) which is in agreement with results described above and the results of [7].

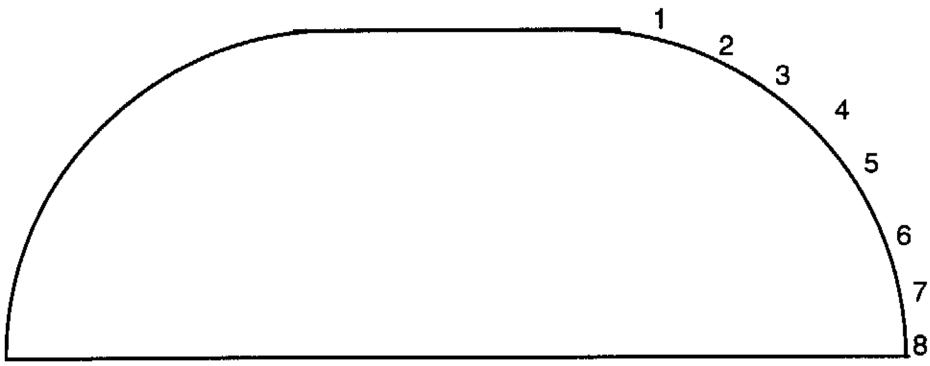

Fig.5 Sample position along the profile of a deep drawn half-cell

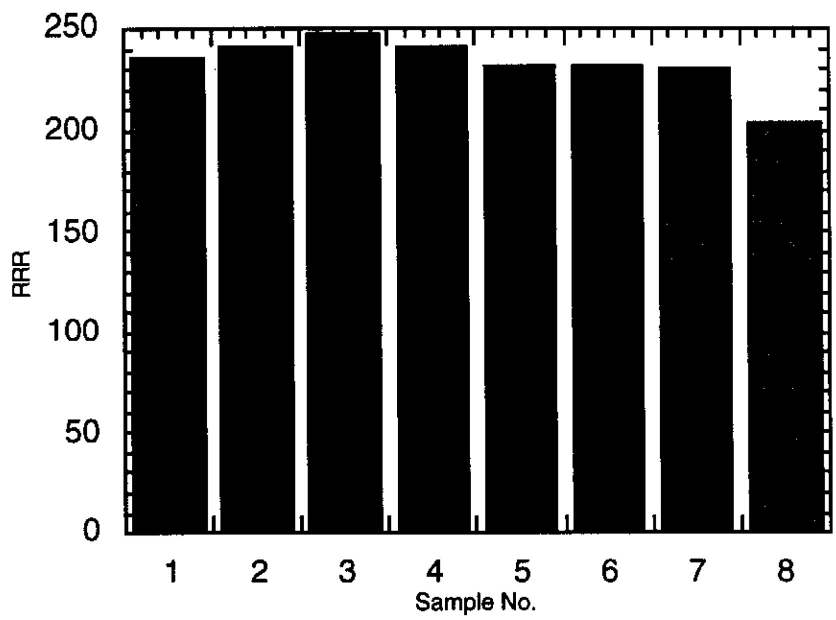

Fig. 6 RRR distribution on a half-cell of cavity

It is well-known that a high deformation (with deformation grade 80-90 %) may reduce the RRR considerably (from 300 to 150). This is caused by increasing of defects in material especially of the dislocation density. The thickness reduction indicates the deformation grade. The wall thickness reduction by the deep drawing of the half cells is small according to Ref. [8] (less than 20%). This can explain the rather small RRR degradation by this fabrication procedure.

RRR Distribution in a Cross-Section of the Nb Sheet

In Ref. [9] the solid state gettering process was described theoretically. After purification a definite distribution of the interstitial impurities in the cross section of the sheet should be expected. The concentration of O, N, C decreases from the center of the bulk to the edges so that the RRR should go up.

It is reasonable to check this conclusion experimentally. Unfortunately we are not in position to carry out a direct RRR measurement of sample layer by layer. For this purpose, an approximate procedure is introduced as following: Nb sample was etched layer by layer, and the RRR was measured after each step. The 4-point method was applied in this case since it is most accurate.

With the RRR values before etching and after etching, the RRR of the etched layer can be found by considering the parallel circuit theory as following:

$$RRR_i = \frac{RRR_{bf} * S_{bf} - RRR_{af} * S_{af}}{S_{bf} - S_{af}} \qquad (1)$$

where

RRR_i - RRR of the etched layer.
RRR_{bf} - RRR of the sample before etching.
RRR_{af} - RRR of the sample after etching.
S_{bf} - cross section of the sample before etching.
S_{af} - cross section of the sample after etching.

We assume that the length does not change during etching because the length is large enough. In practice, it is easier to measure the weight of the sample before etching and after etching. In this case the formula becomes as follows:

$$RRR_i = \frac{RRR_{bf} * W_{bf} - RRR_{af} * W_{af}}{W_{bf} - W_{af}} \qquad (2)$$

where

W_{bf} - weight before etching.
W_{af} - weight after etching.

The RRR distribution in cross section of two Nb samples was investigated. The sample S1 was completely recristallised during the annealing at about 800 °C, the sample S2 was post purified at 1400 °C, 4 hours with a Ti foil being present. The samples were etched in the acid mixture HNO_3:HF:H_3PO_4=1:1:2. Fig.7 gives the RRR after each etching. The RRR of S1 maintains approximately the same value, while RRR of S2 goes down essentially after each etching. With the help of formula (1), the RRR of the etched layers of sample S2 are evaluated. The RRR distribution is shown in Fig.8. It can be clearly seen, that the RRR close to the surface is much higher than that deeper inside of the sample. This behavior is in good agreement with the calculations of [9] and the results presented in Ref. [10].

It should be mentioned that by the eddy current measurements of post purified Nb samples two sides of the sample are normally measured separately. In most cases the RRR results from both sides of the sample are roughly the same. But sometimes the RRR values are quite different as can be seen in Table 1. It seems that the location of the samples in the furnace was not optimal and it was not enough Ti atoms for good gettering effect for one of the sides (with smaller RRR). These circumstances should be taken into account by the arrangement of the cavity solid state gettering.

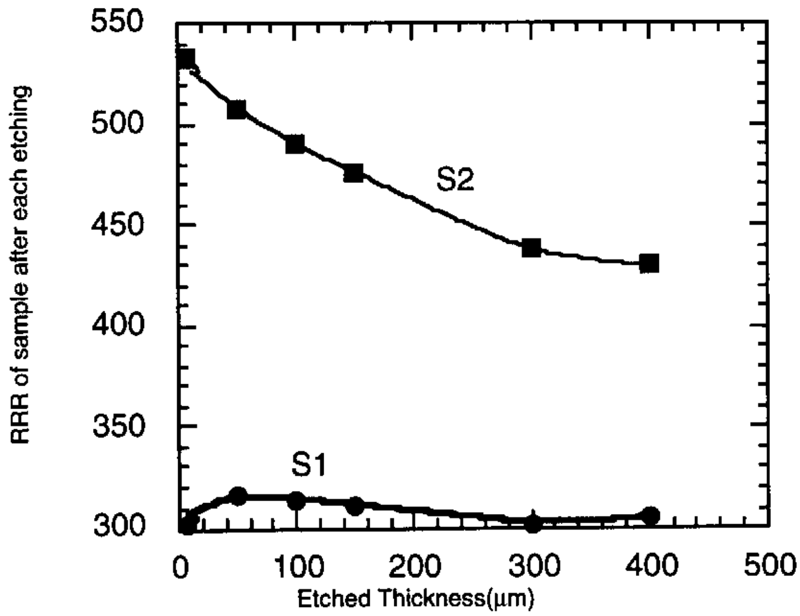

Fig. 7 RRR of the samples after each etching step

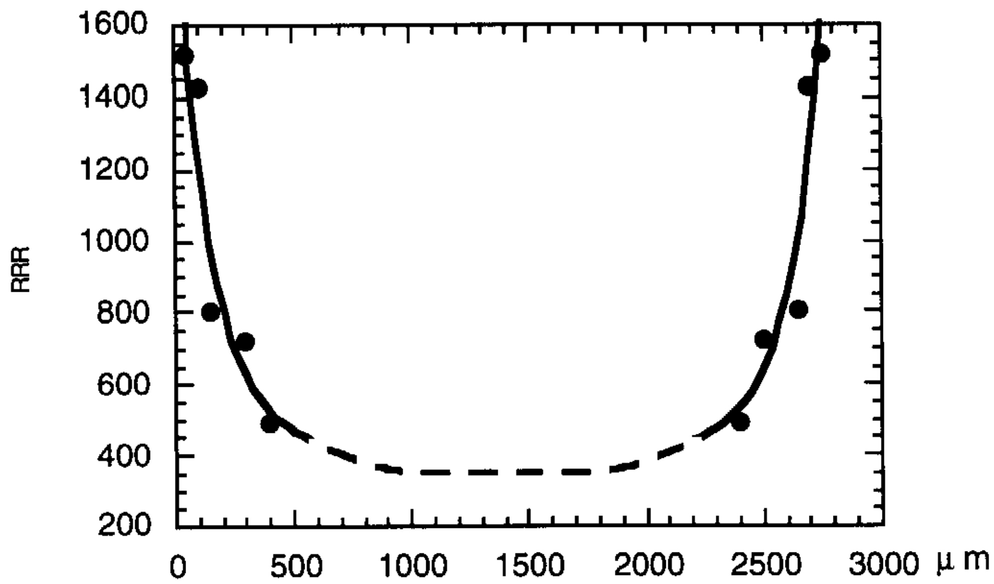

Fig. 8 RRR distribution in the cross-section of the sample S2

Table 1 Eddy current test results on two surfaces of sample

sample	C22_1	C22_2	C22_3
side 1	531	470	487
side 2	624	608	601

Conclusions

1. Eddy current probe can be used for measurement of the RRR value within a small area and for locating bad points in cavity.
2. Reduction of RRR in the welding seam is acceptable for the EB welding, but can not be tolerated for TIG welding.
3. Deep drawing of the TTF half cells does not affect the RRR significantly.
4. The RRR distribution in the cross-section of post purified sample shows that RRR on the surface is bigger than inside and can reach very high values (RRR>1500).

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