ESTIMATION OF SMALL GEOMETRY DEVIATION FOR TESLA-SHAPE CAVITIES DUE TO INNER SURFACE POLISHING

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Abstract

Two well-known polishing methods are used for the inner surface cleaning of superconducting TESLA-shape cavities [1]: electro-polishing (EP) or buffered chemical polishing (BCP). The amount of removed material is relatively small and varies from 5 till 140 µm. The cavity is closed after polishing to prevent scratches or dust appearing on its inner surface. The estimation of the removed material amount is possible by different criteria, for example by comparison of weight before and after cleaning, or by the time - cleaning procedure duration. Both calculations could give us only approximate average value of the removed material amount.

We describe the method for estimation of small geometry deviation basing on RF frequency measurements, which allows calculation of the different influence of surface treatment on the iris and equator areas.

INTRODUCTION

The high sensitivity of RF parameters to cavity geometry deviations is used to determine a very small radius increase due to inner surface polishing.

The out of symmetry axis shift of the half-cell's contour (see figure 1) shows that most of the geometry (volume) changes occur at iris and equator areas. It allows us to separate them in analysis and ignore the region between them.

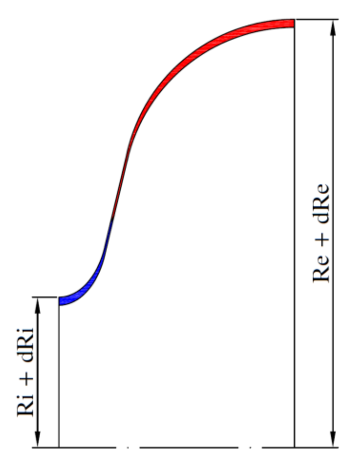
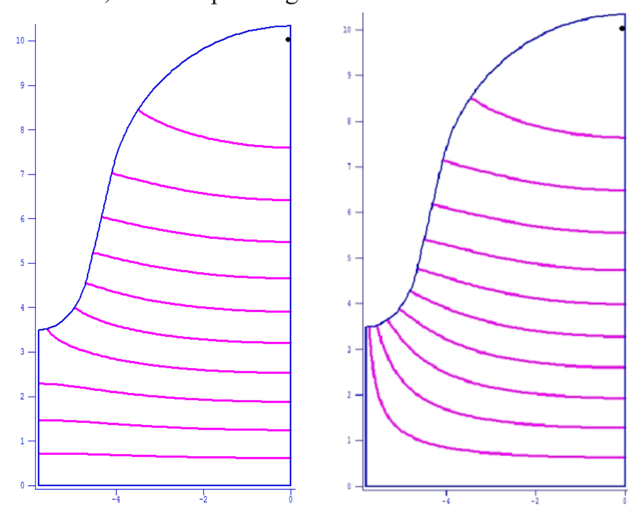


Figure 1: Radius deviations at iris (dRi) and equator (dRe) areas.

METHOD DESCRIPTION

The frequencies are the most sensitive RF characteristics for very small radius fluctuations. To determine the different influence of surface treatment at iris and equator zones we need at least two different independent values.

The boundary frequencies of TM010 (zero and pi-modes) perfectly suit for this goal. They (see figure 2) can be measured for any amount of cells in the cavity starting with two, where separating of "iris" areas exists.



(a) Fo ≈ 1275 MHz (b) Fpi ≈ 1300 MHz

Figure 2: TM010 E-Field distribution for zero (a) and pi-mode (b).

For TESLA-shape cavities with (Ri = 35 mm, Re = 103.3 mm) the sensitivity matrix S define equation (1):

$$\begin{bmatrix} dFo \\ dFpi \end{bmatrix} = S \begin{bmatrix} dRi \\ dRe \end{bmatrix}, \tag{1}$$

where $S = \begin{bmatrix} 0.413 & -14.572 \\ 3.996 & -14.623 \end{bmatrix}$ MHz/mm.

The S-matrix elements have been defined with help of FEM code with boundary approximation of 3-rd order [2]

One can see from equation (1) that both frequencies are very sensitive to cell's radius changes (dRe), but coefficients are very similar (-14.6 MHz/mm). Bore radius variations (dRi) change the coupling between cells. So pi-mode frequency is 10-times more sensitive (4.0 MHz/mm) than zero-mode (0.4 MHz/mm).

Measuring frequency changes dFo and dFpi and using equation (2), one can find the average radius' changes:

$$\begin{bmatrix} dRi \\ dRe \end{bmatrix} = A \begin{bmatrix} dFo \\ dFpi \end{bmatrix}, \tag{2}$$

where $A = \begin{bmatrix} -280.19 & 279.20 \\ -76.56 & 7.91 \end{bmatrix}$ µm/MHz.

One can see from equation (2) that bore radius changes depends mostly on difference between frequency deviations (dFpi – dFo).

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LIMITATIONS

It's very important to realise the limits where this method can be used:

- Sensitivity matrixes S and A are found for TESLA – shape cavities [1] (with Ri = 35 mm, Re = 103.3 mm) and cannot be used for other geometries without corresponding corrections;
- Equation (2) can be used, if frequency changes dFo and dFpi are caused only by radius increase (due to surface polishing). Influences of others factors, like temperature or cavity filling, have to be excluded or strongly reduced;
- This method is based on the assumption that all changes are identical for all cavity cells. No other deformations, like elongations or eccentricity changes, are taking place.

DATA ANALYSIS

The results of polishing and RF measurements are collected in TESLA DB (DESY) [3]. Some of those data taken in the last 6 years are presented in tables 1 and 2.

The estimated values of BCP and EP, which are presented after the calculated values of frequency deviations, were calculated on the basis of process characteristics (like duration of the process) and sample results.

Cavity weight reduction can also be used to calculate the average value of removed material. For example, after the treatment of CAV00500 (last column of table 2) about 180 µm, mass deviation was dM = 1.27 kg. For similar measurements, the averaging or additional calculations can be used to estimate the correspondence between these two parameters. But it gives us only an average value of removed material.

The RF method allows us to find the radius deviations at two locations. For CAV00500 the amount of equator radius increase is about 70 % in comparison with iris: (dRe / dRi = 143 / 202). The average calculated value 180 µm is closer to iris radius deviation 202 µm. The meaning is that treated area is mostly located around iris. This is a normal effect for EP treatment.

For BCP process one can see the opposite effect – the amount of removed material at the equator area is closer to average value. For example cavity AC152 after about 110 µm has dRe = 124 µm and dRi = 172 µm. By the way the ratio between last values is also about 70 %, but usually a little bit higher than for EP.

Table 1: Results of BCP Analysis

Parameters	Units	**Cavities after BCP**							
		CAV00500	CAV00506	CAV00516	AC151	AC152	AC155	AC155	AC155
Date		22.11.2012	08.10.2012	27.06.2013	15.05.2012	25.05.2009	26.05.2010	03.04.2012	11.06.2012
Fo (before BCP)	MHz	1275.024	1275.206	1272.839	1274.792	1271.613	1273.227	1274.983	1274.891
Fo (after BCP)	MHz	1274.763	1275.074	1272.714	1274.710	1269.883	1272.920	1274.891	1274.118
Fpi (before BCP)	MHz	1299.686	1299.765	1297.710	1299.685	1296.809	1297.520	1299.622	1299.553
Fpi (after BCP)	MHz	1299.518	1299.680	1297.615	1299.628	1295.688	1297.308	1299.553	1299.052
dFo	MHz	-0.261	-0.132	-0.125	-0.082	-1.730	-0.307	-0.092	-0.773
dFpi	MHz	-0.168	-0.085	-0.095	-0.057	-1.121	-0.212	-0.069	-0.501
BCP (from [3])	µm	**20**	**15**	**10**	**5**	**>10 +100**	**20**	**8**	**50**
|dFpi| / 10 (kHz/mm)	µm	21	9	10	6	112	21	7	50
dR iris	µm	**26**	**13**	**8**	**7**	**172**	**27**	**7**	**77**
dR equator	µm	**19**	**9**	**9**	**6**	**124**	**22**	**6**	**55**
dRe / dRi	%	71	71	104	83	72	81	100	72
Comments		2 x cold	2 x cold		2 x cold	2 x CTM	2 x CTM?	2 x cold	2 x cold

Table 2: Results of EP Analysis

Parameters	Units	**Cavities after EP**							
		AC114	AC114	AC116	AC152	AC153	CAV00001	CAV00002	CAV00500
Date		18.07 - 01.08.2007	29.10.2007	14-16. 01.2008	17.11.2011	06.12.2010	02-06. 12.2011	07-09. 12.2011	21-28. 02.2012
Fo (before EP)	MHz	1273.176	1272.740	1273.455	1274.486	1272.551	1276.431	1276.710	1274.590
Fo (after EP)	MHz	1272.776	1272.338	1272.143	1274.373	1271.949	1275.294	1275.636	1272.588
Fpi (before EP)	MHz	1297.563	1297.308	1297.838	1299.638	1297.315	1299.706	1299.865	1298.817
Fpi (after EP)	MHz	1297.317	1297.071	1297.052	1299.573	1296.977	1299.037	1299.238	1297.531
dFo	MHz	-0.400	-0.402	-1.312	-0.113	-0.602	-1.137	-1.074	-2.002
dFpi	MHz	-0.246	-0.237	-0.786	-0.065	-0.338	-0.669	-0.627	-1.286
EP (from [3])	µm	**12+12+24**	**48**	**90+50+10**	**12**	**13+48**	**72+48+10**	**72+48+10**	**96+72+10**
|dFpi| / 10 (kHz/mm)	µm	31	30	98	8	42	84	78	161
dR iris	µm	**43**	**46**	**148**	**14**	**74**	**132**	**126**	**202**
dR equator	µm	**29**	**29**	**94**	**8**	**43**	**82**	**77**	**143**
dRe / dRi	%	66	62	64	60	58	62	61	71
Comments		2 x CTM	2 x CTM	2 x CTM	2 x cold	2 x CTM	2 x CTM	2 x CTM	2 x CTM

The analysis was done in range from 5 µm till 180 µm. It was limited only by the statistics in TESLA DB [2].

It's necessary to mention that RF measurements have to be done under the same conditions as described in the previous chapter, but these conditions could be different. Both measurements can be done at room temperature on the cavity tuning machine (CTM) or both at cryogenic temperatures - (cold) measurements.

SUMMARY

The method, based on RF measurement results, is being used successfully at DESY for 15 years.

The most important aspects are:

- it has a good correlation with other estimations of removed material for both inner surface polishing processes: BCP and EP;
- it can be used in a "wide" range of radius changes: from 5 µm till 200 µm;
- it allows us estimation of not only the average value of removed material from the cavity surface, but also for different regions: iris and equator areas.

ACKNOWLEDGMENT

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[3] http://tesla-new.desy.de/cavity_database/summaries/