RF ANALYSIS OF EQUATOR WELDING STABILITY FOR THE EUROPEAN XFEL CAVITIES

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Abstract

In order to guaranty a sufficient High Order Modes (HOM) damping in the European XFEL cavities, a detailed analysis of the mechanical cavity production was performed. The mechanical measurements are precise enough to control the shape of cavity parts, but cannot be used for a welded cavity. To estimate the shape deformation during equator welding, the eigenfrequencies of cavity cells are compared with frequencies of cavity parts. This simple RF analysis can indicate irregularity of 9 equator welds and was used in addition to control of mean values for longitudinal and transverse deformations.

INTRODUCTION

The mechanical and RF characteristics of all cavity parts (Fig. 1) and their positions are very important for field distribution and suppression of HOM [1, 2 and 3].

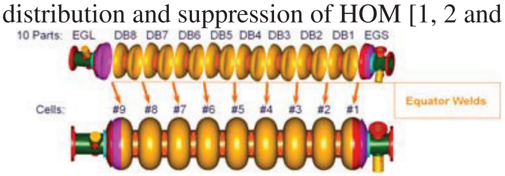

Figure 1: The European XFEL cavity and its parts: dumb-bels (DB) and end-groups (short side EGS, long – EGL).

Different types of deformations during equator welding can be classified as:

- regular (the same for all welds) and irregular (specific for some cells);
- longitudinal and transverse relative cavity axis.

For the European XFEL cavities manufacturing it was planned to analyze only regular deformations (mean values of nine welds) to take them into account for cavities' sub-components preparation (trimming) [4, 5]. Organizing of new mechanical measurements is time consuming and expensive. Thus rapid RF analysis is used to find welding irregularities.

Three factors of frequency changes during equator welding (Fig. 2) have to be taken into account:

1. joint type (material overlapping due to recess);
2. longitudinal deformations due to material melting (shrinkage);
3. transverse local deformation due to outer forces (including gravity) and material softening.

ALGORITHM OF ANALYSIS

The two methods will be described in this part:

- calculation of mean values, which allow us separation of longitudinal and transverse deformations;
- analysis of welds regularity.

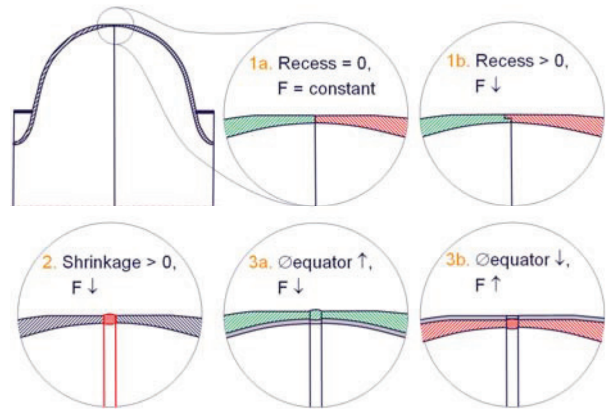

Figure 2: Influence of parts recess (1), shrinkage (2) and transverse deformation (3) on cells / cavity frequency.

Calculation of Mean Values

Based on mechanical measurements, one can calculate longitudinal deformations due to material melting:

$$\mathrm{Sh} = \frac{(\sum_{j=1}^{10} Lj - La)}{18} - R, \qquad (1.1)$$

where: Sh – mean shrinkage per each piece of a weld;

Lj – length of a cavity part ($\boldsymbol{j}$ =1 – $\boldsymbol{L}_{\mathrm{EGS}}$, $\boldsymbol{j}$ =2…9 – $\boldsymbol{L}_{\mathrm{DB\#}(\boldsymbol{j}-1)}$, $\boldsymbol{j}$ =10 – $\boldsymbol{L}_{\mathrm{EGL}}$);

La – length of a cavity after welding;

$\boldsymbol{R}$ – planned recess per each piece of a weld.

Let us assume that we always have a constant recess parameter and any longitudinal deviations of joint between two parts will be counted in shrinkage value.

Calculation of transverse deformation is based on RF measurements:

$$\mathrm{Def} = Fa - \frac{\sum_{j=1}^{10} Fj}{18} - Fl, \qquad (1.2)$$

where: Def – frequency changes per each piece of a weld;

Fj – frequency of a cavity part ($\boldsymbol{j}$ =1 – $\boldsymbol{F}_{\mathrm{EGS}}$, $\boldsymbol{j}$ =2…9 – 2 $\boldsymbol{F}_{\mathrm{DB\#}(\boldsymbol{j}-1)}$, $\boldsymbol{j}$ =10 – $\boldsymbol{F}_{\mathrm{EGL}}$);

Fa – pi-mode frequency of a cavity after welding;

Fl – correction due to longitudinal deformation, estimated in (1.1).

Analysis of Welds Regularity

Frequency changes in cell #($\boldsymbol{i}$), $\boldsymbol{i}$ = 1…9 can be described as:

$$\Delta F(i) = \frac{Fp(i) + Fp(i+1)}{2} - Fc(i), \qquad (2.1)$$

where: $Fc(i)$– eigenfrequency of a cell, which can be found, based on RF measurements (spectra and field amplitudes) after cavity welding [6];

$Fp(j)$ – Frequency of a cavity part ($\boldsymbol{j}$ =1 – $\boldsymbol{F}_{EGS}$, 2…9 – $\boldsymbol{F}_{DB\#(j-1)}$, 10 – $\boldsymbol{F}_{EGL}$).

Average frequency change (2.2) shows mean deformations in all cells:

$$< \Delta F >= \frac{1}{9}\sum_{i=1}^{9}[\Delta F(i) \cdot C(i)], \quad (2.2)$$

where: $\Delta F(i)$ – frequency deviation (2.1);
$C(i) = 1$ – weight factor.

Regularity of cavity equator welds ($\boldsymbol{i}$ = 1…9) can be described by the frequency deviation relative average value:

$$\delta F(i) = \frac{\Delta F(i) - <\Delta F>}{|<\Delta F>|}100\%, \quad (2.3)$$

For irregular welds, if deviation (2.3) is more than 20%, weight factors for these cells have to be changed to $C(i) = 0$ and parameters (2.2…2.3) calculated again.

The existing calculations for regular deformation and their deviations relative average values can be used to determine the direction of irregularities (longitudinal or transverse).

EXAMPLES

The statistics of mean shrinkage for different Nb suppliers was presented in [4, 5] and collected together with results of transverse deformations sotred accortding to the cavity manufacturers in the XFEL cavity database.

The examples of welding irregularities analysis (see Table 1 and Fig. 3) show that the average frequency deviation is below 10 % and the longitudinal fluctuation for a weld does not exceed 0.2 mm.

Table 1: Frequency Deviations in Different Cells

cavity	δF in cells, %								
	#1	#2	#3	#4	#5	#6	#7	#8	#9
CAV00029	2	-6	-69	-1	4	3	-14	15	-3
CAV00057	29	-8	5	6	-4	2	1	4	-7
CAV00871	9	-8	-58	-8	-54	2	-10	0	15

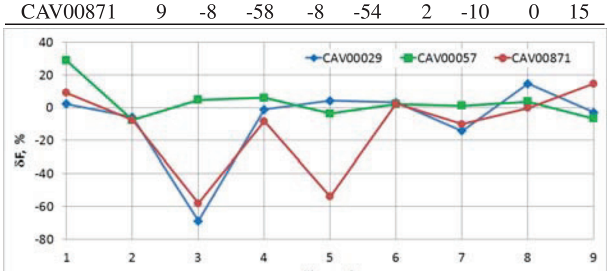

Figure 3: Frequency deviation (2.3) due to deformation during equator welding.

Negative frequency deviation for cavity CAV00029 (cell#3) and CAV00871 (cells #3 and #5) can be explained by additional shrinkage due to double welding of these cells. Cell#1 of cavity CAV00057 has most probably improper parts' joint, which caused the frequency deviation of about 30% higher than average.

Mean values analysis also determined increase of shrinkage value for cavities CAV00029 and CAV00871 about 10 % and reduction – for CAV00057. No transverse deformations were confirmed for any of these cavities.

SUMMARY

Mean values calculation (1.1) and (1.2) for cavity equator welding is performed for the European XFEL. It allows us control of the behavior of the Electron Welding Machines for different material suppliers during cavity mass production. Statistics for two types of deformations (longitudinal and transverse) are used for cavities' sub-components preparation (trimming).

Transverse deformation is usually caused by the force, which join two welding parts together, and gravity. It also depends on cavity orientation during welding:

- vertical cavity orientation usually causes increase of equator diameter and reduction of cavity frequency (Def < 0);
- horizontal orientation – decreases equator diameter and increases cavity frequency (Def > 0), if electron beam comes from the top. Otherwise it is identical to vertical cavity orientation.

Analysis of welding irregularities in different cells of a cavity was developed after beginning of the European XFEL cavities production and was not included in standard procedure.

Uncertainty of irregularity determination is partly caused by the possibility of frequency deviation compensation by different types of deformation (longitudinal and transverse).

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