A SYSTEMATIC ERRORS STUDY FOR THE BEAD PULL MEASUREMENTS

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ABSTRACT

The systematic error for the bead pull measurements in drift tube cavities and disk and washer structure is analyzed. The error is caused by the nonuniformity of the RF field distribution and mirror effect of the spherical bead. The method for error determination is provided which was verified for accelerating system of the Moscow Meson Factory Linear Accelerator (LA MMF). It is shown that the error must be taken into account for the RF field flattering procedure in drift tube cavities. Also this kind of errors is important in coupled cell structures.

INTRODUCTION

The stringent requirements are imposed for accelerating field E_z distribution for a high current proton linac like meson factory. The field distribution needed is achieved by an accelerating cavity tuning. It is known a several techniques for the field distribution measurements. For high quality ($Q = 10^4$) cavities the bead pull measurement [1], which use a small perturbing object, is preferable . For the field measurements in LA MMF tanks spherical perturbing objects are used . Both technique random and systematic errors, and systematic errors, caused by a discrepancy between a real accelerating field distributions and assumptions of a small perturbation method, effects on measurement accuracy. In order to decrease technique errors it is needed to increase the perturbing object - so increasing the shift in cavity resonant frequency δf, but this way give rise to a systematic error effect.

DETERMINATION OF THE SYSTEMATIC ERROR

At the field E_z distribution measurement in multy-gap accelerating structures (drift tube cavity, disk and washer or side coupled tank) the spherical bead size d, which is needed for a stable δf measurement, may be - first of all for a low β - comparable with the length of accelerating gap. It is known that the field distribution in an accelerating gap is nonuniform, and therefore the bead is placed in a nonhomogeneous field. This is first source of the systematic error. The second one - the mirror effect - is displaed when the bead diameter is comparable with distance to drift tube. The string sag - the bead displacement from axis - we taken't into account because usually special supports are used to avoid it. The error is displaed in fall of the relationship $\delta f(d)$ from cube for different values d. We propose the following procedure for the determinations of error:

a) let us calculate changes in frequency for n values of bead radii R_1, R_i, R_n,

b) changes in frequency we represent as:

$$\delta f_i = \sum_{j=1}^{n} a_j R_i^j \tag{1}$$

c) from system of equations

$$\begin{gathered} \delta f_1 = \sum_{j=1}^{n} a_j R_1^j \\ \cdots\cdots\cdots\cdots \\ \delta f_n = \sum_{j=1}^{n} a_j R_n^j \end{gathered} \tag{2}$$

we find a value of a_3 coefficient and estimate methodical error as:

$$\frac{\delta E}{E} = \sqrt{\frac{\delta f_i}{a_3 R_i^3}} - 1 \tag{3}$$

Realisability of the procedure proposed depends critically on the accuracy of frequency f_n calculations. After consideration, modern numerical code MULTIMODE [2] was choosen.

ESTIMATION OF THE FREQUENCY CALCULATION ACCURACY

The code MULTIMODE was developed with using finite elements method and is intended for frequency calculations at axiallysymmetric cavities. Construction elements, disturbing an axial symmetry, for example, supports in drift tube cavity, are presented in an accelerating structures. Nevertheless these elements are choosed such that not disturb the field distribution for an operating mode. Testing calculations were done because there isn't possibility to obtain analytical estimations for the calculation accuracy. We consider the spherical cavity with small metallic sphere in the center. An analytical solution for frequency and electromagnetic field distribution in spherical cavity is known. Considering a small sphere as bead and calculating the frequency change we can estimate the accuracy of the proposed prosedure. Calculation show, that in range of spheres radii relation from 0.006 to 0.036 product of relative frequency shift due to small sphere on error of this shift calculation is equal $(0.5\text{-}1.0)*10^{-7}$. In order to obtain reliable data about δE it is need to have the absolute error of $\delta E/E$ determination not worse then 10^{-3} and, therefore, the perturbing sphere must give the relative frequency change not less then $5.0*10^{-4}$, that is limitation from below on the perturbing sphere diameter. To obtain a high accuracy, the special procedure of calculations and data process was developed, which is described in detail in Ref.[3]. Leaning on testing results, we considered for calculations a perturbing sphere with such size, that provides accuracy of $\delta E/E$ determination about 0.1% for DAW structure and 0.3% for drift tube tank. Comparison of calculated systematic error with experimental results (Fig. 1) for several first gaps of first DTL tank LA MMF shows a good agreement for such precise measurements and calculations.

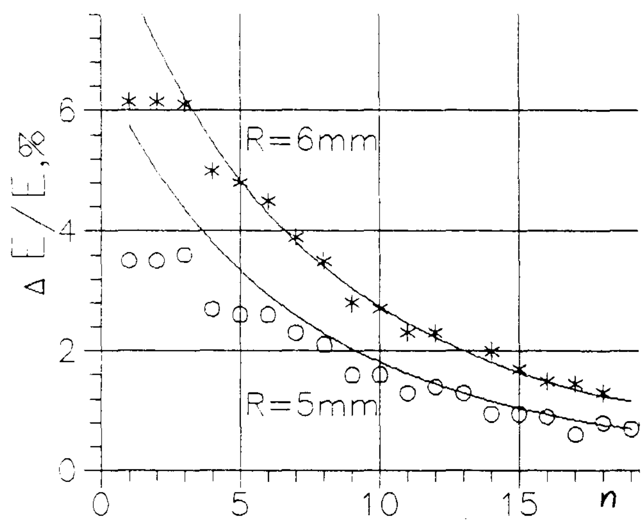

Fig. 1. Calculated (solid lines) and experimentally estimated (points) systematic error of the field distribution measurements in first DTL tank. n - number of the accelerating gap.

THE ERROR OF FIELD DISTRIBUTION MEASUREMENTS FOR THE DAW STRUCTURE

With using of the procedure described, the error of field measurement in cell was calculated both for the bead sphere position at the center of an accelerating gap and for sphere displacement along the beam axis. E_z field distribution becomes more quietly as β increases and therefore the error decreases. Decreasing of $\delta E/E$ is a most notice for large R>0.5a, (R - radius of the perturbing sphere, a - radius of aperture), see Fig. 2 . The error is

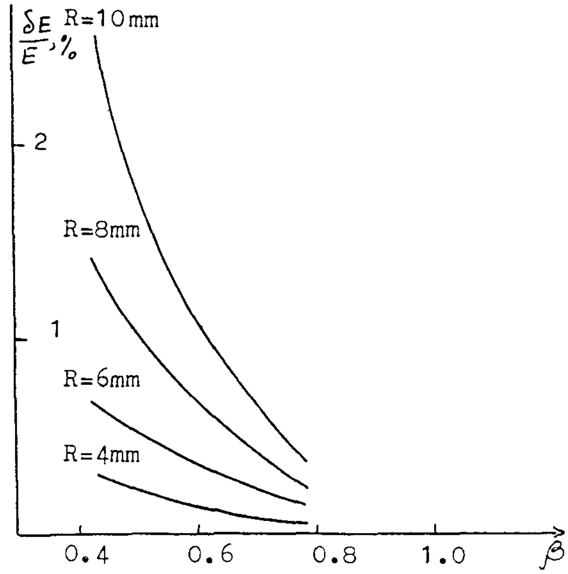

Fig. 2. Dependence of $\delta E/E$ vs β for measurements in the DAW structure. Perturbing sphere is in the center of the accelerating gap.

minimal at the center of an accelerating gap and is maximal at the edge, see Fig. 3. Usually tanks of accelerating structures on high β consist of cells with the same β. If so, the error is the same for all cells and not effect substantially on results of RMS and tilt accelerating field determination. The dependence $\delta E/E$ from sphere placement can exert an indirect effect for finding of the accelerating gap center. It is obvious that $\delta E/E$ is determined by a relationship between the sphere size and dimensions of accelerating structure elements near beam axis, which are choosed for achievement of maximal shunt impedance. Therefore, at the same frequency dimensions of elements near the beam axis for the DAW structure are the same as for another high -β structures and results of $\delta E/E$ calculation are suitable for them.

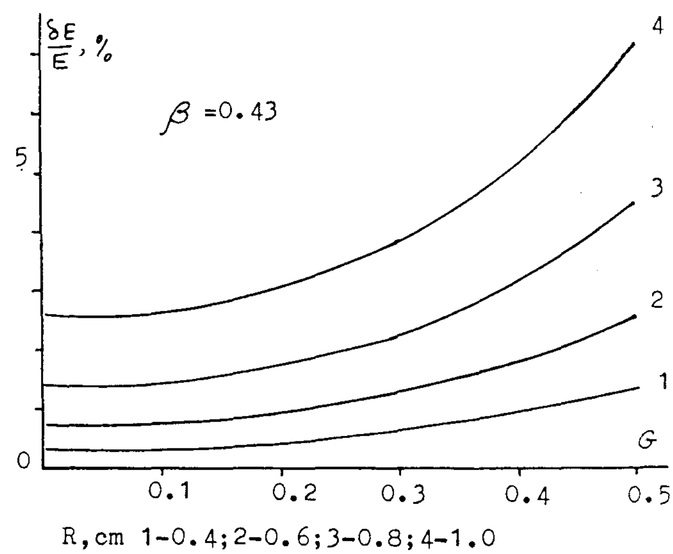

Fig. 3. Dependence of $\delta E/E$ vs displacement of the bead sphere from the center of the accelerating gap in the DAW structure. G is the length of the gap.

THE ERROR FOR DRIFT TUBE CAVITY

Lengths of periods and accelerating gaps in the drift tube cavity are extending. For example, in first DTL tank of LA MMF length of the gap rises from 15 at the beginning to 133 mm at the end. The field distribution measurement error depends on the gap length critically. From Fig. 4 for first DTL tank LA MMF one can see, that for gaps in the beginning of the tank the error a highly great, because it is need to use spheries with a large radius (> 5 mm). It is known, that for accelerating gaps with large length (at high β) accelerating field distribution along the axis has two maxima, placed symmetrically from the gap center. In this case the $\delta E/E$ error changes sign as the radius of perturbing sphere increases, see Fig. 5. This dependence permits to recommend for field unflatness measurements in cavities with a high length of gaps a large enough spheres in order to minimize both random and systematic field measurements errors. More detail information about $\delta E/E$ dependencies on size and placement of perturbing sphere for LA MMF accelerating tanks is given in Ref. [3].

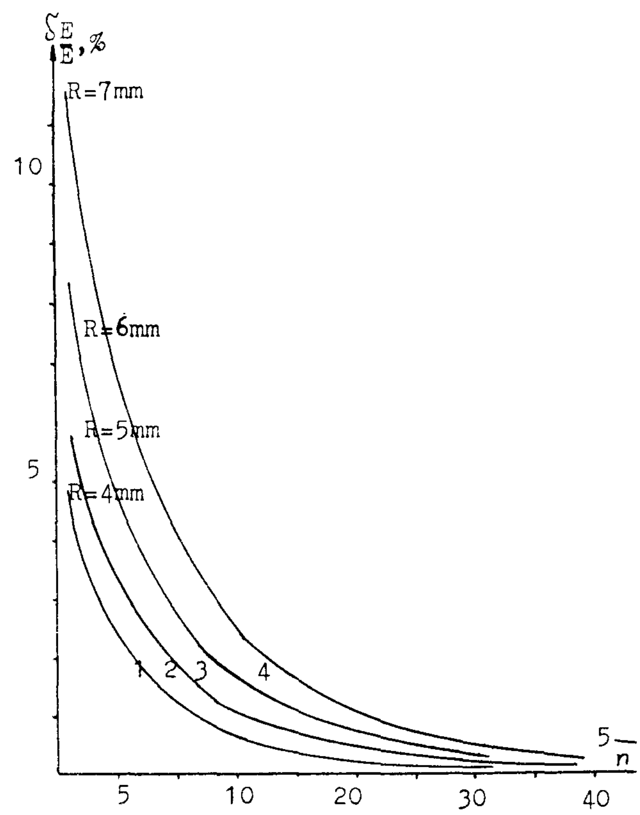

Fig. 4. Systematic error of the field distribution measurements in first DTL tank. n - number of the accelerating gap.

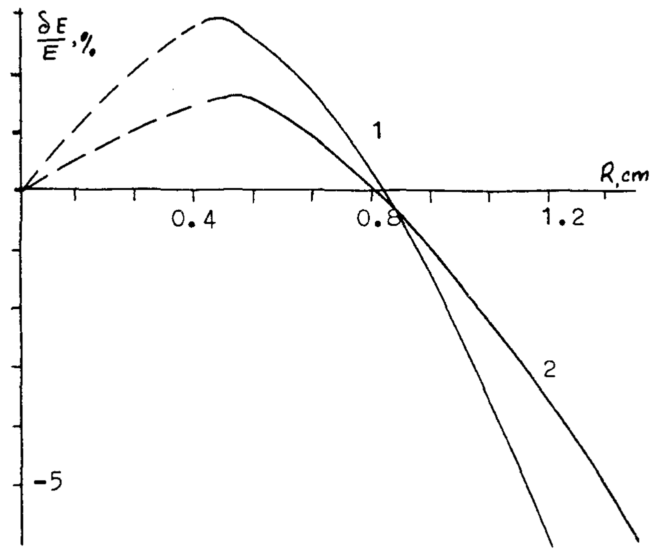

Fig. 5. Dependence of $\delta E/E$ vs sphere radius in fifth DTL tank for displacements from the center 1 - G/6, 2 - G/3.

CONCLUSION

The procedure of the systematic error estimation of the accelerating field distribution measurements with using a perturbing sphere for bead pull technique is proposed. It is shown, that is need to take into account the systematic error for drift tube linac cavity tuning if an accelerating gap length is comparable with a bead size. At large accelerating gap lengththe systematic error changes the sign as radius of a perturbing sphere is increased. It permits to choose a large sufficiently size of the perturbing sphere, thus decreasing both random and systematic errors. Results of this work are suitable for different linac accelerating structures with geometrically similar elements near the beam axis.

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