Measurement of Transverse Electric Field Gradient in Non-Axisymmetric Structures

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Abstract

A technique of electric field transverse gradient (FTG) measurement for non-axisymmetric structures (NAS) is developed. It's based on the resonance perturbation method. Small frequency shifts are registered by automatic measurement installation. A program for experimental data treatment was developed. This program enables to minimize errors arising at calculation of second derivative of accelerating electric field fundamental harmonic amplitude by transverse coordinates. Test measurements carried out on a rectangular disk loaded waveguide (RDLW) show that the error is less than 10%. Measurements results for structures with different disk slot shapes are presented.

The measurement of the FTG in NAS is based on the reactive probe technique. The measurements of resonant frequency change are carried out by transverse along structure axis z at two perpendicular planes (x,z) and (y,z). Values of the amplitude of the fundamental harmonic of the longitudinal electric components $E_{z0}(x,0)$ and $E_{z0}(0,y)$ are calculated using the measurement results. The second derivative of this dependence along x and y normalized on the field amplitude at the structure axis accordingly is called as normalized field transverse gradient (NFTG):

$$G_x(x,0)_n = \frac{\partial^2[E_{z0}(x,0)/E_{z0}(0,0)]}{\partial x^2}$$

$$G_y(0,y)_n = \frac{\partial^2[E_{z0}(0,y)/E_{z0}(0,0)]}{\partial y^2}$$

And at the case of concrete examples the next expressions are used [1]:

$$G_x(x,0) = -\frac{1}{\omega} E_{z0}(x,0)\cdot G_x(x,0)_n \sin\varphi_0$$

$$G_y(0,y) = \frac{1}{\omega} E_{z0}(0,y)\cdot G_y(0,y)_n \sin\varphi_0$$

Small shifts of the resonant frequency are measured by automatic measurement installation [2] in S-band. A rather tiresome procedure of measurement results treatment with the aim of NFTG calculation prompted to develop a system connecting the measurement installation with a personal computer as well as an experimental data treatment code. The measurement installation consists of four elements; an amplifer-autogenerator, a frequency-meter, a device for probe support and replacement, a personal computer with a printer and a display.

The experimental data treatment code consists of some parts that may be used for the treatment different modes and structures.

S-band resonant assemblies consisting of five identical cells and two half-cells were developed and studied for the purpose of testing the NAS electrodynamic characteristic measurement method. A resonant assembly on the basic of RDLW was investigated at this aim. RDLW has sizes as 110*55 mm^2 and rectangular slot 104.5*15*5 mm^3. The RDLW was chosen as a test model because there were analytical expressions for its characteristic [1].

$2\pi/3$ mode oscillations are exited in the RDLW at 3171 MHz frequency with the relative phase velocity value β_{ph}=1.0 and that of group velocity β_{gr}=0.027. The quality factor of a resonant structure made of copper turned out to be Q~4500.

The fundamental harmonic is calculated on a period that equals wave length and also $3D$ (D is the structure period) for $2\pi/3$ mode. The experimental distribution $f_0(z)=f_0-f(z)$ obtained for a disk loaded waveguide (DLW) is presented in fig.1.

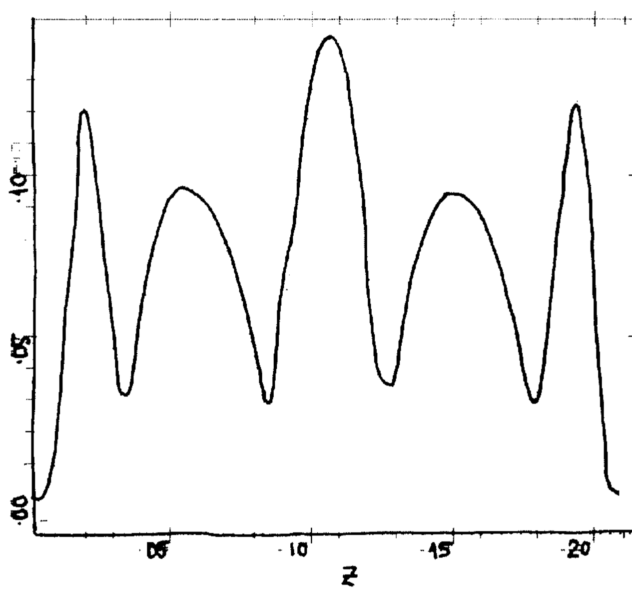

Figure 1. The experimental distribution $E_{z0}\sim\sqrt{f(z)}$ for DLW

It's seen that $f_0(z)$ is asymmetric relative to the antinode at a structure center. The treatment of experimental results included the point located to the left and to the right from the maximum $f_0(z)$ over interval $3D$ so that such an asymmetry influence on treatment results would be diminished. Furthermore in the process of preliminary calculations a considerable dependence of the fundamental harmonic amplitude on errors in determination of nodes and antinodes position was noted. So further computation precision enhancement the determination of polarity change points in the dependence $f_0(z)$ were conducted by means of least squares method (LSM). In such case 15 points massive were calculated.

By constant motor velocity of the device for probe support and replacement the registry installation possibilities allow to measure along z-axis with step no lesser than 0.38 mm, and in our case we obtain near 300 points per period. There is the possibility of thread displacement along x and y-axis with step no lesser than 0.5 mm. The total time of one measurement series (displacement along z-axis of structure by different deviations $\Delta x, \Delta y = \pm 3$ mm with 0.5 mm step along x and y-axis and the treatment) is equal to $\sim$30 min. It's necessary near $2\frac{1}{2}$ hours for the full series of 5 measurements for one structure.

Now we'll consider the precision of NFTG measurement. It should be noted that $E_{z0}(x,y)$ slightly depends on the measurement step z, if $z \leq 0.9$ mm (see Tabl.1). So in most cases $z = 0.573$ mm was chosen.

Table 1
The dependence $E_{z0}(x,y)$ versus discretisation step

z mm	3.82	2.29	1.53	0.92	0.76	0.57	0.38
E_{z0} rel.unit	199.7	198.9	198.1	197.5	196.8	196.4	196.3

The dielectric probes have a cylindrical shape and were made of high-frequency ceramic with relation a length to a diameter equals 10:1 and with directness along axis z K_N=7...10 perturbs practically only z-component of electric field E_z. It's clear from results of measurements with probes that have different values of K_N. For two probes with l_1=12.2mm, d_1=1.2mm and l_2=11.5mm, d_2=1.05mm experimental values of form-factor equal k_{z1}^e=2.952e-19 m^2s/Ω and k_{z2}^e=1.723e-19 m^2s/Ω accordingly, i.e. there are a different K_{N1}=9 and K_{N2}=7. The values of NFTG obtained with this probes equal -1735 $1/m^2$ and -1715 $1/m^2$ accordingly for NAS a/λ= 0.09. This confirms our assumption. But also it's necessary to take into account that influences of other field components on a result of electric-field z-component fundamental harmonic measurement was used for taking into account of this fact and for the NFTG calculation at different coordinates x,y. For example the weight of value $E_{z0}(0,0)$ is equal to 1, and the weight of value $E_{z0}(x,0)|_{x=3mm}$ equals $\sim$0.75.

A systematic measurement errors connected with placing and tuning of the device for probe support and replacement were avoided by using the treatment of experimental data. The $E_{z0}(x,y)$ dependence is normalized to the analytical value $E_{z0}(x_1,y_1)$ obtained by LSM approximating of experimental data where x_1 and y_1 are analytical coordinates of structure axis. Its may be no equal 0.

The errors of smoothing out arises by LSM approximating of fundamental harmonic for calculation of analytical dependence $E_{z0}(x,0)=F(x^2)$ and $E_{z0}(0,y)=F(y^2)$ and its derivativeness with aim of NFTG obtaining. In assumption of E_{z0i} normal distribution at given x_i and y_i one can obtained that the mean squared error of NFTG computation doesn't exceed 10%.

There are limited possibilities of assemblies creating with different slot height and β_{ph} equals 1 exactly. So the NTFG dependence on phase velocity β_{ph} was investigated. The β_{ph} deflection at the $\pm$0.02 range causes NFTG deflection at the measurement errors range.

It can be seen that the difference between experimental NFTG value for RDLW

$$\frac{G_x(0,0)}{E_{z0}} = -0.55\cdot 10^{-7}\ s/m^2$$

$$\frac{G_y(0,0)}{E_{z0}} = 0.39\cdot 10^{-7}\ s/m^2$$

and analytical NFTG value [3]

$$\frac{G_x(0,0)}{E_{z0}} = \frac{G_y(0,0)}{E_{z0}} = 0.50\cdot 10^{-7} s/m^2$$

is negligible and is at the range measurement errors. So this method may be used for NFTG determination for NAS.

For the NAS geometry proposed for linear collider the measurements of FTG were carried out. The structures with slot for beam path at the range a/λ =0.07...0.19 were investigated and measurement results are shown in fig.2 .

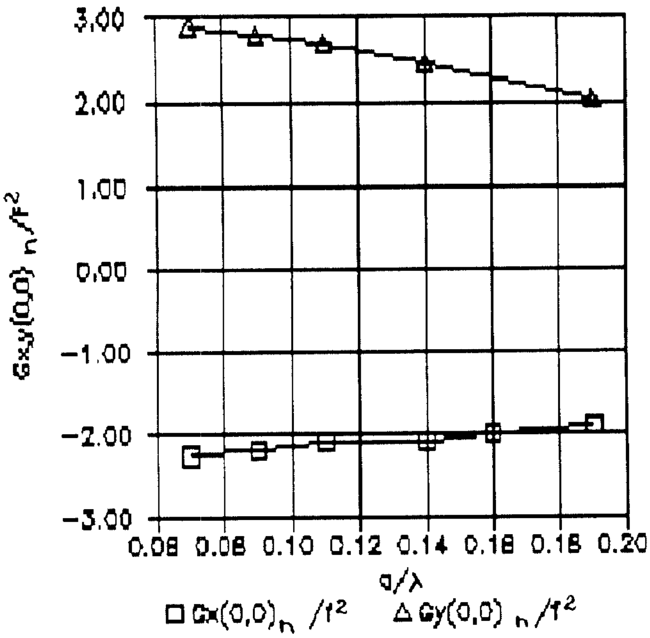

Figure 2. Dependences of $G_x(x,0)_n/f^2$=F(a/λ) and $G_y(0,y)_n/f^2$=F(a/λ) for the non-axisymmetical slot structures ($\beta_{ph}=1, \theta=2\pi/3$, f=2796 MHz)

References

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