CALCULATION AND EXPERIMENTAL INVESTIGATION OF ELECTRODYNAMICS CHARACTERISTICS OF SBLC DLW

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Abstract

In this paper the electrodynamic characteristics of the 6 meter SBLC accelerating section with constant gradient are considered. The values of resonant frequencies, longitudinal and transverse shunt impedances, Q-factor for the fundamental and first dipole modes were calculated using MAFIA code and also were measured by small perturbation method with disk and cylindrical probes. The results measurements and calculations for the first and last SBLC DLW cells are presented.

Electrodynamics characteristics at the fundamental mode.

Two sets of cells for the input (cell N1) and output (cell N178) ends of 6-m long section Disc Loaded Waveguide of S-Band Linear Collider (SBLC DLW) [1] were fabricated. All measurements of ElectroDynamics Characteristics (EDC) were carried out by means of those cell sets since the resonance measuring units were assembled on the basis of cells with the same dimensions. Before measurements some calculations were conducted with the using of programs URMEL-T and MAFIA [2]. To simplify the calculation procedure and obtain more complete information in particular at π phase shift on some cells there were no rounding. The absence of rounding decreased the effective shunt impedance. from 45.13 to 43.27MΩ/m for cell N1 and from 61.32 to 58.85MΩ/m for cell N178. Other EDC were changed insignificantly. But in the case without rounding we can assemble resonant sections consisting of several full cells and half-cells at the ends. For such sections with electrical walls at the ends one can calculate the EDC at the frequencies corresponding to π-mode of the fundamental and hybrid modes

Experimental studies were carried out with resonant sections consisting of 6 similar cells with dimensions corresponding to the first and the last cells of 6m long SBLC DLW (its first version where $2a$ for the first cell equals 31,02 mm and for the last one 21,77 mm). Measurement of resonance frequencies, Q-factors and longitudinal and transverse shunt impedance were conducted according to the technique [3]. For the measurement of shunt impedance at dipole mode frequencies a device was developed and fabricated which could provide the relative frequency stability 10^{-7} in the range from 4 up to 6 GHz The results of EDC measurement for two mentioned resonant sections operating in the fundamental mode are presented in detail for the DLW cell with $2a$=21.77 mm . According to the handbook on DLW [3] one for the structure under consideration the following parameters can be predicted: $\beta_{gr2/3}$=0,0128,

$$\frac{E_0\lambda_{2/3}}{\sqrt{P}} = \xi_{e.t.} = (485 \pm 20)\Omega^{1/2},$$

$$\frac{r_{sh\,\|}}{Q} = \frac{\beta_{gr\,2/3}}{2\pi\lambda_{2/3}}\xi_{e.t.} = 4{,}77\frac{k\Omega}{m}.$$

where $\beta_{gr2/3}$ is group velocity at 2π/3 mode, $\lambda_{2/3}$ is wave length in free space corresponding to 2π/3 mode, E_0 is first harmonic amplitude of accelerating field, P is input power, r_{shII} is longitudinal shunt impedance.

The value of Q was equally 14700. At Q=13200 the value of $r_{sh||}$ is equal to (63±3)MΩ/m.

The measured values of frequencies and Q-factors at those modes are given in Table 1. All the cells were tuned to the 0-mode frequency with the error ±0,1 MHz before measurement of the longitudinal shunt impedance.

Table 1
The measured values of frequencies and Q-factors for the SBLC DLW with 2a=21.77mm.

θ	0	π/6	π/3	π/2	2π/3	5π/6
f, MHz	2966	2968,9	2977,9	2987,6	2997,8	3007
Q±600	9400	9400	9400	10000	10700	9700

Fourier analysis of the field distributions was carried out for the middle part of the section over three cell length. For θ=2π/3 the relative amplitude of the main harmonic has been determined to be

$$A_1 = \sqrt{\Delta f_0} = 4652Hz^{1/2}.$$

The form-factor of the bead used for the measurements appeared to be

$$K_e = (0.84 \pm 0.01) \bullet 10^{-19}\ \frac{m^2 s}{\Omega}.$$

The electrical field strength parameter for the resonant section of DLW has been defined as

$$\eta_{e.s.} = \frac{A_1}{\sqrt{2\pi K_e f_{2/3}^2}} = (214 \pm 10)\frac{\Omega^{1/2}}{m}.$$

For the traveling wave case the electric field strength parameter is introduced as ($L = 2\lambda_{2/3}$)[4] :

$$\xi_{e.t} = \eta_{e.s.}\sqrt{\frac{\pi L \lambda_{2/3}^2}{\beta_{gr2/3}}} = (471 \pm 18)\frac{\Omega^{1/2}}{m}.$$

As for the parameter $\frac{r_{sh\|}}{Q}$ it can be written as

$$\frac{r_{sh\|}}{Q} = \frac{1}{2}\eta_{e.s}^2 = (4.58 \pm 0.3)\frac{k\Omega}{m}$$

and for $Q = 13200$ one can obtain $r_{sh\|} = (60.5 \pm 3)\frac{k\Omega}{m}$. Note, that at $a/\lambda_{2/3} = 0.109$ the cells should be finely tuned to their own frequency to obtain good field symmetrization.

The longitudinal shunt impedance at the fundamental mode of DLW first cell was measured with the use of metallic and dielectric cylinders. The measurements were carried out for 2π/3 and π modes. The calculation of $r_{sh\|}$ was based on the determination of the ratio $r_{sh\|}/Q$. If Q-factor was equal 14500, the longitudinal shunt impedance at 2π/3 mode was 48.1MΩ/m (measured by metallic bead) and 44-49MΩ/m (measured by dielectric bead). At the π mode these values were 43.5MΩ/m and 38.8Mπ/m correspondingly.

Electrodynamics characteristics at hybrid mode.

In the beginning of study of the first dipole mode EDC for the structure which consists of cells similar to the last one of SBLC DLW (2a=21.77mm) preliminary individual tuning of each cell to the frequency of the hybrid wave 0-mode was have again carried out. It should be noted that even slight defect of a cell caused arising of not strongly expressed resonance of the second dipole mode. The resonant frequency of the hybrid wave was measured in the assembled prototype consisting of 6 tuning cells. The measured values of frequencies and Q-factors are presented in Table2.

Table2.
Frequencies and Q-factor versus phase shift for the first dipole mode of DLW SBLC with 2a=21.77mm.

θ	5π/6	2π/3	π/2	π/3	π/6	0
f ±0.05, MHz	4464	4482	4509	4546	4583	4601
Q_0 ±500	9500	9200	9000	9000	9000	9200

Experimental data of the dispersion curve for the first dipole mode SBLC DLW with 2a=31.02mm are shown in Table 3.

Table3
Data of the frequencies vs. phase shift.

θ	0	π/4	π/2	3π/4	π
f,MHz	4184.0	4151.1	4127.4	4119.5	4117

These data were obtained experimentally on the resonant prototype consisting of 3 full specially shaped cells (the cell surface is rounded) and two half-cells without rounding. We have used such a structure because it is not possible to excite the first dipole mode with π phase shift in the structure consisting of full cells. The half-cells diameter was determined on the prototype exited at the fundamental mode with 2π/3 phase shift. The dispersion relation indicates that π-mode and neighboring 3π/4-mode have frequencies which differ only by 2.4MHz. It results in complications in the study on the basis of small perturbations method. For obtaining the correct electric field pattern in the prototype, consisting of 3 full cells and 2 half-cells, we have to retune individually the prototype elements with high precision (about 0.02 MHz). Moreover, the choice of perturbing bodies is also limited because maximal perturbation should not exceed 0.5MHz. That limits the directness coefficient of the perturbing body.

The transverse shunt impedance $r_{sh\perp}$ was determined in terms of the longitudinal shunt impedance $r_{sh\,\|}$ according the formulae:

$$r_{sh\perp} = \frac{r_{sh\,\|}}{(kr)^2}, \quad (1)$$

where k is the wave number in the free space.

Using MAFIA program the values of $r_{sh\,\|}$ and $r_{sh\perp}$ were obtained for π-mode and other mode of the first dipole wave of the first and last DLW cells. The knowledge. of $r_{sh\perp}$ and $r_{sh\,\|}$ values at modes different from the π-mode is helpful for the precise determination of $r_{sh\perp}$ at frequencies corresponding to the hybrid wave phase velocity equal to the light velocity. The results of $r_{sh\perp}$ calculation by MAFIA code are in satisfactory agreement.

The ratio of the longitudinal shunt impedance to the Q-factor as a function of the distance from the structure axis, obtained with by MAFIA program is shown in Fig.1. The calculations were carried out for the structure, consisting of 3 full cells and 2 half-cells with dimensions 2*a*=31.02mm, 2*b*=81.38mm, *D*=33.33mm, *t*=5mm. There were no rounding of the disk apertures and cell inner surfaces. It is clear that such a structure differs from one experimentally studied. But this calculation is more simple due to the absence of rounding.

The following results were obtained: $\frac{r_{sh\perp}}{Q} = 1300\frac{\Omega}{m}$ at π-mode and $\frac{r_{sh\perp}}{Q} = 500\frac{\Omega}{m}$ at 3π/4-mode.

Similar computations were conducted by means of URMEL-T program for the structure, consisting of 3 full cells with rounding and 2 half-cells without rounding. The value of $\frac{r_{sh\perp}}{Q}$ at π-mode had appeared to be 700Ω/m.

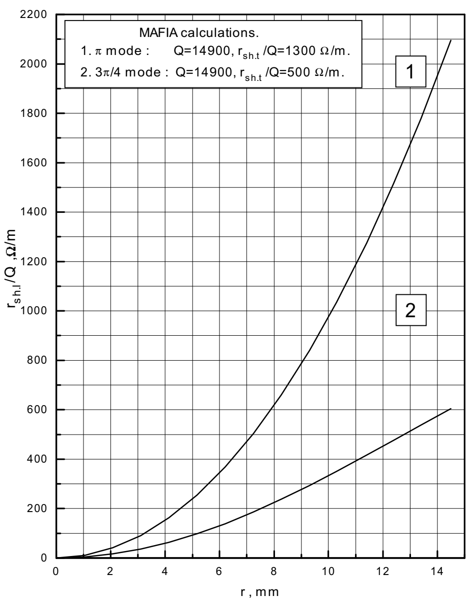

Fig.1. Relation of longitudinal shunt impedance to Q-factor vs distance from the axis for DLW with 2a=31.02 mm ,

Measurements of the transverse shunt impedance in the structure, consisting of three full cells and two half-cells, were carried out by means of disk and cylinder shaped perturbing bodies. The form-factor of disk shaped perturbing body with diameter 3.5mm and thickness 0.5mm was $k_r^E = (0.483 \pm 0.015) \cdot 10^{-19} \frac{m^2 s}{\Omega}$. Calculations of experimental data with using of the fundamental harmonic have given the following result: $r_{sh\perp}$/Q=(639±60)Ω/m. At *Q*=13000 the value of transverse shunt impedance $r_{sh\perp}$=(8.3±0.8)MΩ/m. Similar measurements were carried out with cylindrical perturbing body which had length 6mm, diameter 0.7mm, form-factor k^E_z=0.944x$10^{-19}$$m^2$s/Ω, and directness coefficient k_d = 7±1. In this case we have the result: $r_{sh\perp}$ /Q=(805±110)Ω/m. At Q=13000 $r_{sh\perp}$=(10.4±1.5)MΩ/m.

Comparison of experimental and calculated values of the transverse shunt impedance at π mode (Table 3) shows the experimental ones are somewhat lower like it was for the case of SBLC DLW with 2a=21.77mm

The transverse shunt impedance values calculated by MAFIA code (last version) in DESY was 9.9 MΩ/m for cell with 2a=31.02mm and 14.9MΩ/m for cell with 2a=21.77mm. The experimental result for cell with 2a=21.77mm was equal 11.5MΩ/m.

Table4.
Experimental and calculated data of the transversal shunt impedance (MΩ/m) of SBLC DLW cell with 2a=31.02 mm for θ=π (Q=13000,)

Experimental data		Calculated data	
disk bead	cylinder bead	MAFIA	URMEL
7.8÷8.3	10.4	16.9	10.0

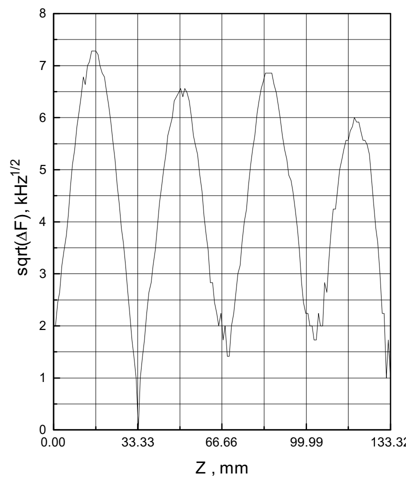

Fig.2. E_r field distribution versus position of the disk bead on the axis of structure SBLC DLW with 2a=31.02mm (Θ=π).

Conclusion.

We investigated the electrodynamics characteristics of the SBLC accelerating structure. The resonance frequencies, Q-factor, longitudinal shunt impedance were measured at the fundamental and first dipole modes for the first and last cells of DLW. The values of transverse shunt impedance was measured by small perturbation method with disk and cylindrical probes and also were calculated by MAFIA code.

References.

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