INTEGRATED TUNING OF DIELECTRIC ELEMENTS OF ACCELERATING STRUCTURES

G.A. Bryzgalov, V.G. Papkovich, N.A. Khizhnyak
NSC KIPT, Kharkov,
Ukraine, 61108, Kharkov, Akademicheskaya, 1
e-mail: papkovich@kipt.kharkov.ua

The method based on a longitudinal waveguide dielectric resonance for tuning dielectric elements of slow-wave structure cells is reported. The cells with dielectric disks are tuned by compensating the permittivity spread and technological tolerances through the selection of the dielectric disk width. The method provides tuning of disks in the cells to accuracy no worse than 0.01 MHz for the general working frequency of the structure. This method is applicable for determining integrated characteristics of dielectric elements (effective permittivities) in microwave devices that can be used, for example, for the development of exit windows for high power microwave flows.

PACS numbers: 29.17.+w

1 INTRODUCTION

A periodically loaded metal diaphragms - or dielectric disks - waveguide physically represents a set of the large number of single cells. In case of a metal waveguide the cell can consist of a ring and diaphragm or an asymmetrical continuous cup with the central aperture. An internal ring diameter is equal to a waveguide diameter. The coupling aperture is determined by a designed operating wavelength, its mode and phase velocity under the chosen constant diaphragm thickness. The cell length is determined by an accelerating structure period. As a rule an individual tuning of a diaphragmatic waveguide cell is carried out by selection of the internal waveguide diameter at a composite resonator model [1]. Cell tuning accuracy by such a method is at a level of 0.1 MHz for the modern electron linear accelerator.

At transition from the periodic waveguide metal structure to dielectric one in the simplest variant [2] metal diaphragms are replaced by dielectric rings. Presence of dielectrics with a relative dielectric permittivity ε in the cell volume puts a number of specific problems at the tuning of single cells for the general structure frequency. It is caused by several factors – dielectric parameters variation throughout the disk volume (a transit channel presence, inhomogeneity of disk material) and a choice of a disk thickness as a tuning parameter as a more technological one in the case.

2 TUNING FEATURES OF DIELECTRIC STRUCTURE ELEMENTS

Dielectric disks for an accelerating structure are made of separate ceramic slugs. Technological spread when preparing various parties of slugs (milling initial ceramics component, temperature condition of baking, other technological processes) results in the spread of dielectric permittivity both between single prepared parties of slugs, and inside the single party. Measurements of dielectric permittivity carried out over test ceramic disks have shown that a dielectric permittivity spread between single parties can achieve several units, and in the disk volume a variation of dielectric permittivity has been observed up to unit (between central and peripheral areas). Measurements of dielectric permittivity are carried out by a method of resonant electromagnetic wave scattering on a dielectric sphere into a rectangular waveguide [3].

Presence of the transit channel along a system axis results in reduction of dielectric loading in the system. It should be noted, that unlike the diaphragmatic waveguide the transit channel radius r_0 in a dielectric structure can be prescribed arbitrary. As a rule, it gets out proceeding from two main conditions: $r_0 < \lambda_g / 2$ and $r_0 < b/2$, where λ_g is the wavelength in a waveguide, b is the dielectric disk thickness.

For operating at a 10 cm wave band the characteristic dimensions of dielectric disks with $\varepsilon = 90$ (titanium dioxide ceramics) are: the external disk diameter ~ 80 mm, the transit aperture diameter ~ 5 mm, the disk thickness ~ 2,7 mm at a wave phase velocity in the structure $\beta_{ph} = v_{ph} / c = 1$.

A tuning of dielectric disks for working frequency is carried out by a resonant method. A phenomenon waveguide-dielectric resonance (WDR) is known to be observed in a single dielectric sample placed into an evanescent waveguide on condition that

$$f_{res} = f_c \sqrt{\frac{\varepsilon^2 + 1}{\varepsilon(\varepsilon + 1)}}, \qquad (1)$$

where f_c is the critical frequency of a hollow waveguide, [4]. In a waveguide periodically loaded with dielectric disks a phenomenon of longitudinal waveguide-dielectric resonance (LWDR) is observed under a wave phase shift between adjacent disks $\psi = \pi / 2$ [5]. We can tune dielectric disks for the given frequency f_c by selection of their thickness, having a predetermined required waveguide radius $R_c = \dfrac{c\sigma_0}{2\pi f_c}$ from the condition of the resonance (1), where c is the light velocity, and σ_0 is the first root of

Bessel's function of the zero order.

The behavior of dispersive curves for the loaded dielectric disks waveguide is shown in Fig. 1 at the various periods of disks arrangement (1-L = 8 mm; 2 - 15 mm; 3 - 27 mm).

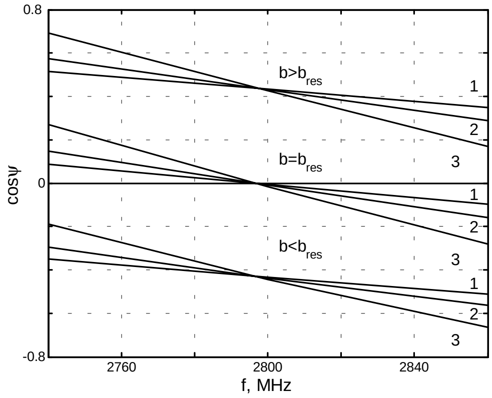

Fig. 1.

The initial resonant thickness of dielectric disks is estimated by loading the waveguide with solid disks

$$b_{res} = \frac{c}{4\varepsilon_{eff} f_{res}} \sqrt{\frac{\varepsilon_{eff}^{\ 2} + 1}{\varepsilon_{eff} - 1}}\,, \qquad (2)$$

where $\varepsilon_{eff} = \varepsilon\left[1 - \frac{1}{2}\ln(\varepsilon)\left(\frac{r_0}{R}\right)^2\right]$ is the effective dielectric permittivity of disks taking into account the central channel.

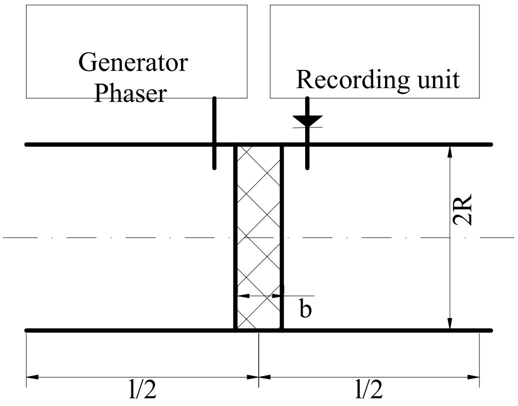

Fig. 2.

A schematic diagram of dielectric disks tuning setup is shown in Fig. 2. The dielectric disk in a metal holder is placed into a circle evanescent waveguide consisting from two identical sections in length $l/2$. In the system the mode E_{01} is excited with the help of probes. The wave, reradiated by a disk, excites a probe of a transducer signal that is detected, amplified and registered. Waveguide section lengths are selected such that the reflectings from the ends of the system were minimum. In our case the influence of opened section ends at the disk resonance frequency did not exceed ±0.03 MHz at the total length $l = 1200$ mm. The measurement of frequency is carried out with the help of a carrier of frequency and electronic-countable frequency counter. Accuracy of manufacturing the waveguides and a disk diameter is in limits ±0.01 mm, for a disk thickness of ±0.002 mm. The system temperature is supported to be constant during measurements.

The results of the experimental studying the dispersing characteristics of a loaded identical dielectric disk structure are shown in Fig. 3 depending on the period of their arrangement (disk resonance frequency is 1 - $f_{res} = 2799.00$ MHz; 2 - 2798.27 MHz; 3 - 2797.99 MHz; 4 - 2796.80 MHz).

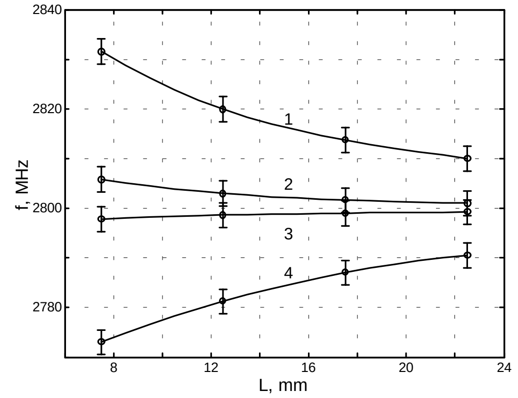

Fig. 3.

A resonance frequency of the mode E_{01} was evaluated taking into account the effective dielectric permittivity for a multielement system (2800 MHz) that corresponds to the experimental results obtained.

The developed method of tuning dielectric disks has allowed rather promptly and with a big accuracy to tune dielectric structure cells for the given frequency. Besides also the inverse problem is solved easily - at the known LWDR frequency and the disk thickness it is possible to determine a material effective dielectric permittivity value. The method can find application also for tuning the dielectric window output for powerful microwave sources.

REFERENCES

1. O.A.Val'dner, N.P.Sobenin, B.V.Zverev, I.S.Shchedrin. *The reference book on diaphragmatic waveguides*. M.: Atomizdat. 1977, 376 p. (in Russian).
2. Ya.B.Fainberg, N.A.Khizhnyak. Artificial anisotropic media // *ZTF*. 1955, v. 25, #4, p. 711-719 (in Russian).
3. N.A.Khizhnyak. *The integrated equations of macroscopical electrodynamics*. Kiev: "Naukova Dymka", 1986 (in Russian).
4. V.A.Korobkin, N.A.Khizhnyak. A waveguide-dielectric resonance of a dielectric sample in a rectangular waveguide // *Izv. VUZov. Radiophysics*. 1978, v. 21, # 4, p. 558-565 (in Russian).
5. V.G.Papkovich, G.A.Bryzgalov, N.A.Khizhnyak. A longitudinal waveguide-dielectric resonance in systems with artificial anisotropic loading // *ZTF*. 1980, v. 50, # 2, p. 409-410 (in Russian).