ISBN: 978-3-95450-197-7 doi:10.18429/JACoW-RUPAC2018-WEPSB52

AMPLITUDE-PHASE CHARACTERISTICS OF A THIN DIAPHRAGM IN A RECTANGULAR WAVEGUIDE

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Abstract

A model of a thin diaphragm in a rectangular waveguide is discussed. Expressions for determining the amplitude-phase characteristics of the diaphragm are presented. The position of the diaphragm nearest basic reference plane is determined, where the reflection coefficient is a real negative number. The basic reference plane is shown theoretically and experimentally to be on the right side of the diaphragm, i.e. outward from the generator. The obtained relationships are shown to allow the amplitude-phase characteristics of the diaphragm to be experimentally determined using the measuring line.

INTRODUCTION

Diaphragm is an orifice plate mounted transversely to the axis of a waveguide to blank off it. Diaphragms are used as inlet and outlet units of resonators, filters, accelerating systems [1, 2]. Diaphragm characteristics or, in other words, loads with complex reflection coefficient usually are considered in terms of the method of equivalent circuits by treating the diaphragm as the reactivity across the line (waveguide) [3, 4]. Physically adequate description of interference phenomena in the waveguide at wave scattering from inhomogeneities is allowed by the method of incident and reflected waves [5]. This method was used for considering the thin diaphragm. The reflection from the diaphragm produced a standing wave in the waveguide. The minimum position was determined using the measuring line, and the measurement results were used for calculation of modules and phases of reflection and transition coefficients of the diaphragm.

BASIC RELATIONSHIPS

Thin Diaphragm in a Rectangular Waveguide

We give relationships to determine amplitude-phase characteristics of a thin diaphragm in plane of its geometrical arrangement in a rectangular waveguide.

Let wave with amplitude a falls to the diaphragm. When so, another two waves emerge in the waveguide; these are reflected and transmitted waves of respective amplitudes Γa and Ta, where in-plane coefficients Γ and T can be shown in complex form:

$$\Gamma = |\Gamma| e^{i\psi}, \mathrm{T} = |\mathrm{T}| e^{i\theta} \quad (1)$$

Here |Γ| and ψ are module and phase of the reflection coefficient; |T| and θ are module and phase of transition coefficient. In the absence of losses, the following equations can be written for the thin diaphragm [4, p. 144; 6]:

$$1 + \Gamma = \mathrm{T} \quad (2)$$

$$|\Gamma|^2 + |\mathrm{T}|^2 = 1 \quad (3)$$

The first equation follows from boundary conditions on the diaphragm, the second from the energy conservation law. Complex coefficients **Γ** and **T** can relate to radius-vectors on the complex plane. Relations (2) and (3) also are valid for these vectors **Γ** and **T**. In equality (2), if move **Γ** to the right and square all the expression, then the scalar product of vectors **Γ** and **T** with regard to (3) gives:

$$(\mathbf{\Gamma}, \mathbf{T}) = 0 \quad (4)$$

Move the origin of radius-vector **Γ** to point (1,0) in the complex plane. In accordance with expressions (2), (3), (4) we have diagram [6] that characterizes the amplitude-phase properties of the diaphragm:

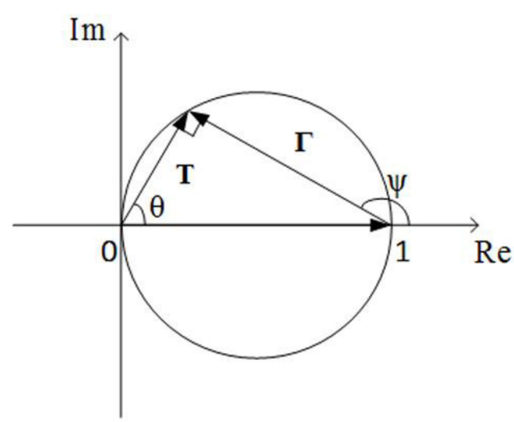

Figure 1: Amplitude-phase diagram of the diaphragm.

Diaphragms are classified into inductive, capacitive and resonant. In Figure 1, points in the unit diameter circumference correspond to multitude of inductive and capacitive diaphragms in the waveguide. The further consideration will concern inductive diaphragms because they are used for connection of inlet resonators of accelerating structures with the fill line. The points in the upper semiplane of the circumference correspond to the inductive diaphragms: $\pi \geq \psi \geq \frac{\pi}{2}$ and $\frac{\pi}{2} \geq \theta \geq 0$. Geometrically, Fig. 1 allows the following relationships:

$$\psi - \theta = \frac{\pi}{2} \quad (5)$$

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$$sin\psi = |T|, sin\theta = |\Gamma|, cos\psi = -|\Gamma|, cos\theta = |T| \quad (6)$$

$$tg\psi = -\frac{|T|}{|\Gamma|}, tg\theta = \frac{|\Gamma|}{|T|} \quad (7)$$

Thus, if we know one of characteristics of the thin inductive diaphragm, then can find all the rest characteristics from equations (5), (6) and (7), i.e. describe completely the thin inductive diaphragm in the waveguide.

Basic Reference Plane of an Inductive Diaphragm in the Rectangular Waveguide

In accordance to equation (1), the amplitude-phase characteristics of the diaphragm in plane of its geometrical arrangement are imaginary numbers. Let us find the position of the diaphragm closest reference plane where its coefficient is the real negative number. This plane will be referred to as basic.

Derive expression determining the position of the basic reference plane of the inductive diaphragm in the waveguide.

A standing wave emerges in front of the diaphragm applied to the waveguide. If the position of the diaphragm is considered the reference point, then by definition the following can be written for the reflection coefficient in an arbitrary point z<0 of the left of diaphragm:

$$\Gamma(z) = |\Gamma|e^{i(2kz+\psi)} = -|\Gamma|e^{i(2kz-\Delta\psi)} \quad (8)$$

Here $\pi - \psi = \Delta\psi > 0$ is auxiliary angle, $k = \frac{2\pi}{\lambda}$ is wavenumber, λ is wavelength in the waveguide. It follows from equality (8) that the reflection coefficient is real number on condition

$$2kz - \Delta\psi = \pi n, n = 0, \pm 1, \ldots \quad (9)$$

According to (9), z is minimal at n=0; therefore, the coordinate of the basic reference plane for the inductive diaphragm is determined as

$$z_0 = \frac{\Delta\psi}{2k} \quad (10)$$

Hence, the basic reference plane is in the point at $z_0 > 0$. The actually reflected wave, and thus coefficient Γ, exists only at $z < 0$. However, the wave may be considered reflected from a conditional plane with coordinate z_0 since this plane characterizes correctly the amplitude-phase properties of the diaphragm.

MESURING TECHNIQUE

The above described model of thin diaphragm in a rectangular waveguide was checked using experimentally determined position of the basic reference plane with respect to the diaphragm; the results were compared to expression (9). The basic plane position was determined using the measuring line. To describe the measuring technique, let us consider two objects: a short-circuiting plate and a thin diaphragm inserted alternately in the waveguide at point z=0. A standing wave emerges in front of each of them. The interference pattern is shown in Fig. 2.

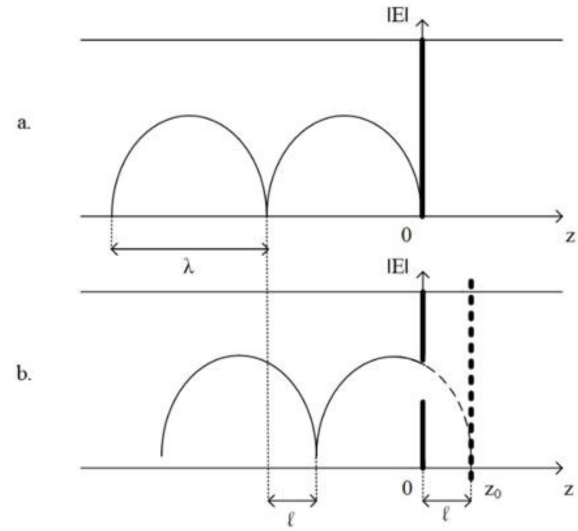

Figure 2: The standing wave in front of the short circuit and thin diaphragm.

The standing wave in front of the short circuit is illustrated in Fig. 2a. There are coinciding minimum of the standing wave and the short circuit plane. In this basic reference plane of the short circuit, its reflection coefficient $\Gamma = -1$, the real negative number. In the case of the inductive diaphragm described by relationship (10), the standing wave is shaped as shown in Fig. 2b. Fig. 2 demonstrates that the position of the basic reference plane shifts rightward with respect to the diaphragm and is determined by expression:

$$z_0 = l \quad (11)$$

Here l is the shift of minimum of the standing wave in line upon substitution of the diaphragm for the short circuit. In accordance to expression (9), the reflection coefficient in the basic reference plane of the diaphragm is

$$\Gamma = -|\Gamma|,$$

i.e. the real negative number.

Thus, the diaphragm parameters were determined using the measuring line. The line (waveguide) was shorted off using a plate, and the position of the minimum of the standing wave was determined using a traveling probe at the chosen frequency of 2450 MHz. The diaphragm was mounted instead of the shorting plate and applied the required load. The position o the minimum of the standing wave was determined again with the traveling probe. The shift of the minimum positions was used for determining l.

RESULTS OF MESUREMENTS

Three thin diaphragms (3 mm in thickness) chosen for the measurements were plates with close to rectangular holes for wave transmission.

Figure 3 shows the standing wave amplitude depending on coordinates for the short circuit (1) and for the

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diaphragm with 10×40 mm^2 hole (2). The minima of the standing waves formed upon the diaphragm mounting are seen to shift rightward against the nearest minima formed with the short circuit. The amplitude of the incident wave is not normalized.

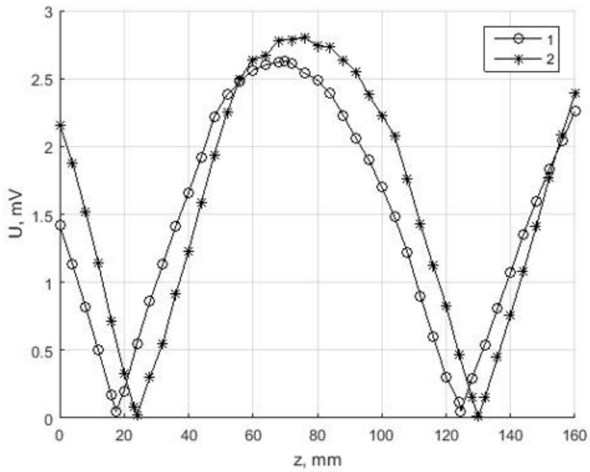

Figure 3: Standing wave amplitude depending on coordinates. 1- short circuit, 2- diaphragm 10×40 mm^2.

Different methods were used for determining modules of transmission coefficients for each of the diaphragms. The first method was the direct measurement using an Agilent N5230A instrument. The second was calculations of the module by formulae (10), (6) after the position of the basic reference plane was measured with the measuring line. Geometrical dimensions of the diaphragm holes and the transmission coefficient modules obtained by two methods are given in the Table 1.

Table 1: Diaphragm Characteristics

Hole size, mm^2	lTl (instrument)	lTl(measuring line)
10×20	0.021 ± 0.004	0.01 ± 0.02
10×30	0.089 ± 0.003	0.10 ± 0.02
10×40	0.24 ± 0.02	0.28 ± 0.02

CONCLUSIONS

The pattern of the standing wave obtained by measuring its amplitude as a function of the coordinate along the waveguide (Fig. 3) coincides qualitatively with the theoretical pattern (Fig. 2b). Figure 3 shows the shift of the minimum of the standing wave rightward. Thus, both theoretical and experimental studies demonstrate that the basic reference plane of the diaphragm is on the rite side of the wave.

The applied method for measuring the diaphragm parameters shows correctly the interference pattern at the wave scattering on the diaphragm. The measurement of the shift of the standing wave minimum allows all the diaphragm parameters to be determined. The error in measuring the transmission coefficient increases with a decrease of the diaphragm hole in size because the shift of the diaphragm minimum against the minimum of the short circuit becomes comparable with the instrumental error.

When the diaphragm hole is larger than 30 mm, the relative error is less than 10 % that is appropriate for practice. Rather high accuracy of the model is see in the Table 1; hence, the model under consideration also is appropriate for adequate description of the diaphragm properties at the range of low transmission coefficients.

ACKNOWLEDGEMENT

The work was supported by the Russian Scientific Foundation (project No. 17–73–30032).

REFERENCES

[1] C. G. Montgomery, R. H. Dicке and E. M. Purcell. Principles of Microwave Circuits. McGraw-Hill, New York. 1948. Sovetskoe Radio, Moscow. 1951.
[2] Th. P. Wangler. RF Linear Accelerators. WILEY-VCH. 2008.
[3] L. Lewin. Advanced Theory of Waveguides. London. 1951. Radio i Svyaz’, Moscow. 1981.
[4] M. M. Karliner. Microwave Electrodynamics. Course of Lectures. NSU, Novosibirsk.1999. [in Russian].
[5] J.L. Altman. Microwave Circuits. D. Van Nostrand, New York. 1964. Mir, Moscow. 1969.
[6] Yu. D. Chernousov, A. E. Levichev, V. M Pavlov, G. K. Shamuilov. Thin Diaphragm in the Rectangular Waveguide. Vestnik NSU. Series: Physics. V.6, № 1, p. 44. 2011. [in Russian].