APPLICATION OF NUCLEAR METHODS

https://doi.org/10.46813/2024-153-092

UDC 621.317.329

AN EFFICIENT HIGH POWER WATER DUMMY LOAD AT 2.45 GHz

A.G. Nahornyi, S.A. Yeryomin, V.A. Baturin, D.A. Nahornyi
Institute of Applied Physics of National Academy of Science, Sumy, Ukraine
E-mail: ipfmail@ipfcentr.sumy.ua

A water dummy load developed as an element of equipment in the composition of a microwave atmospheric pressure plasmatron operating at a frequency of (2450±50) MHz is described. The load is created on the base of a rectangular waveguide with a cross-section of 90x45 mm. The simulation results carried out by CST Microwave Studio shows that the return losses reach -42 dB at 2.45 GHz. In the frequency band from 2 to 2.9 GHz, the load provides a voltage standing wave ratio (VSWR) of at least 1.2. The effect of changes in water temperature and salinity on the device characteristics is studied. The load is manufactured and successfully used as part of experimental waveguide paths.

INTRODUCTION

Waveguide matched loads are widely used in the terminal paths of electronic equipment. A particularly important task is to develop loads for high-power paths (>1 kW) [1, 2]. In our case, such a load was required when developing a microwave atmospheric pressure plasmatron. A modified magnetron generator from a household microwave oven was used to power the plasmatron. The operating frequency of such a generator is (2450±50) MHz, and in the original version it has air cooling and a pulsed mode of operation. In the process of modifying the microwave generator, it was necessary to ensure its continuous operation with water cooling. To test the corresponding modes, a matched load was required that was capable of absorbing the generated power for a long time (about 10 h) at a reflected power level not exceeding 10%, which corresponds to a voltage standing wave ratio (VSWR) of no more than 1.2. An analysis of literature data and advertising offers showed that the most suitable in our case is a water load, i.e. a load in which the absorption of microwave power is carried out directly by cooling water.

The prototype for the design of the developed device was the water load described in [3] and designed and manufactured by The Ferrite Company, Inc. at 915 MHz. A similar construction is also described in [4].

1. DESCRIPTION OF THE WANER LOAD DESIGN

The appearance of the water load is shown in the photograph Fig. 1. The device consists of a section of a copper rectangular waveguide with a cross-section of 90x45 mm and a length of about 150 mm. At one end, the section has a standard connecting flange, and at the other it is closed with a short-circuiting plug. Near the short-circuited end, the waveguide is connected to cylindrical metal pipe (internal diameter 46 mm, length 150 mm) containing water. The water is isolated from the internal volume of the waveguide by means of a hollow cone made of Teflon. The Teflon cone in its upper (wide) part is sealed with a rubber gasket with a pipe. The lower (tapering) part of the cone is immersed in the waveguide to approximately half the height of its narrow wall.

Fig. 1. General view of water load

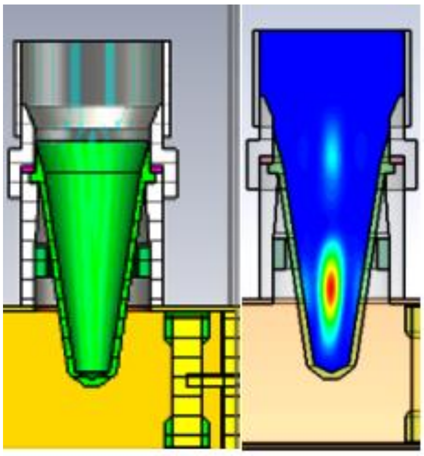
A metal tube with a diameter of 6 mm and a length of 120 mm is inserted through the plug in the upper part of the pipe. Cooling water enters the large pipe through it. Water goes out through another hole in the plug.

In addition to the described elements, a tuning element in the form of an inductive pin is located inside the waveguide section between the Teflon cone and the short-circuiting wall. The pin can move along the axis of the waveguide by means of a special mechanism

The absorption of radiation by water is determined by the orientation of polarized molecules. The counteracting effects are intermolecular interaction and thermal motion of molecules. As a result, the absorption of radiation by water changes with the change in the radiation frequency and depends on the temperature of the water. These factors had to be taken into account first of all when designing the load.

2. CST MICROWAVE STUDIO MODEL

The computer model of the load, created by means of the CST Microwave Studio program, is shown in Fig. 2,a in the form of a section by a plane parallel to the narrow wall of the waveguide, along its axis. This angle allows for the most complete understanding of the details of the structure under study. Only the part of the model that is important for further discussion is shown. The parts made of Teflon are highlighted in green; the sealing ring made of rubber is marked in red.



a *b*

Fig. 2. Water load model (a) and power loss density distribution (b)

The Teflon hollow cone has a total length of 65 mm, and a diameter at the top of 37 mm. The thickness of the cone walls is 2 mm. The geometry of the cone, especially the ratio of the upper and lower diameters, was optimized during a special simulation step. Then, a real sample of the cone was made from a solid piece of Teflon by turning. Finally, the computer model was adjusted according to the dimensions of the real cone. The design features of the real metal water pipe taken into account.

In the lower right part of Fig. 2,a, the above-mentioned inductive tuning pin is visible. Its diameter is 10 mm, with its ends the pin rests on the wide walls of the waveguide through Teflon gaskets 1 mm thick, due to which it can easily and without sparking move along the axis of the waveguide. At the same time, sufficient capacitive coupling of the ends of the pin with the walls of the waveguide is ensured.

Another element to pay attention to is the Teflon washer that encircles the cone and fits tightly into the bottom of the pipe. Like all Teflon parts, it is marked in green in Fig. 2,a. The outer diameter of the washer is 18.5 mm (according to the inner diameter of the lower section of the pipe), the inner diameter is 15 mm, the height of the washer is 10 mm. During the simulation process, the location of the washer along the vertical axis is selected in such a way as to obtain the desired characteristics of the device.

In the computer model, excitation of the device is assigned through the port simulating the presence of the dominant TE_{10} mode in the input waveguide cross-section.

The model also assumes that the absorbing medium is uniform and unmoved; in other words, water circulation within the load is not considered.

3. RESULTS AND DISCUSSIONS

Fig. 2,b shows the calculated distribution of microwave power loss density. It clearly shows that power absorption occurs practically within the volume of the cone. The spot in the upper part of the cone is associated with the penetration of microwave radiation along the dielectric walls of the cone, but the main part of the power is absorbed in its lower part. This circumstance allowed us to exclude the volume of the upper part of the metal pipe with water from the calculations, thereby reducing the calculation time.

Note that a similar result was obtained using the Quick Wave program in [3].

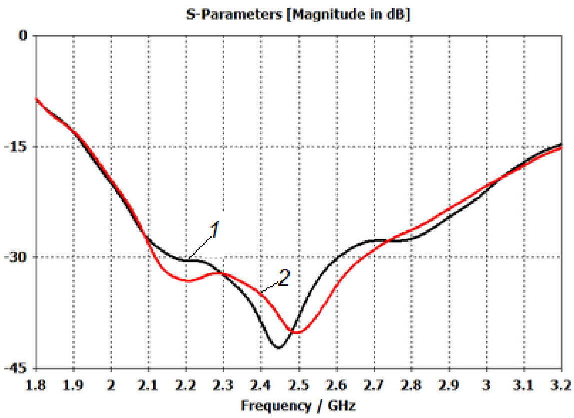


Fig. 3. Return loss simulated by CST for different water temperatures: 1 – 25 ^{0}C; 2 – 50 ^{0}C

Fig. 3 shows return losses simulated by CST in the frequency range from 1.8 to 3.2 GHz (curve 1). This dependence is calculated for clean fresh water at a temperature of 25 ^{0}C.

The minimum on curve 1 reaches -42 dB and corresponds to a frequency of 2.45 GHz. Such results were achieved by selecting the optimal depth of immersion of the cone with water in the rectangular waveguide, selecting the optimal geometry of the cone, and finally, selecting the positions of the inductive pin and dielectric washer.

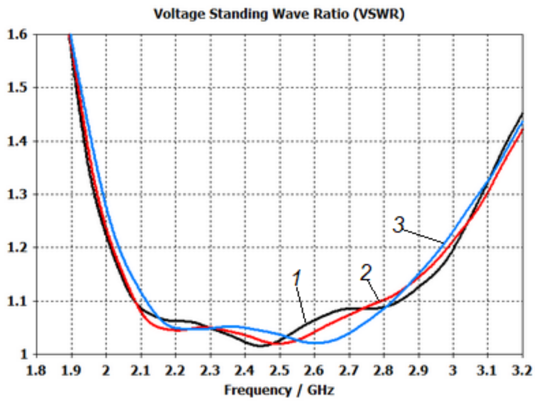


Fig. 4. Frequency dependences VSWR for: 1 – fresh water at 25 ^{0}C; 2 – fresh water at 50 ^{0}C; 3 – sea water at 25 ^{0}C

Due to the high power density released in the volume of water, its temperature does not remain constant. It is well known that the permittivity and conductivity of water change with temperature [3–5]. Inevitably, the characteristics of the water load also change. Curve 2 in Fig. 3 corresponds to a water temperature of 50 ^{0}C. It is evident that the frequency dependence of the return losses changes, but this does not lead to any fatal consequences. This is especially clearly confirmed by the curves in Fig. 4, which show the frequency dependences of the VSWR for various conditions.

Curve 1 (black) corresponds to fresh water at 25 ^{0}C. For it, at a frequency of 2.45 GHz, the VSWR is 1.016 and, accordingly, the return losses are -42 dB. Curve 2 (red) describes the frequency dependence of the VSWR of fresh water at 50 ^{0}C. Its value at a frequency of 2.45 GHz is 1.033 (corresponding return losses are minus 38 dB). Finally, curve 3 is a variant of sea water at 25 ^{0}C. We have a VSWR of 1.04 at the same frequency and return losses of -33.3 dB. Of course, the use of sea water to absorb microwave power in our conditions is not realistic, but this calculation illustrates the low criticality of the developed load to the quality of the pumped water.

It also follows from curve 1 that the VSWR limit level we have chosen, equal to 1.2, is ensured in the frequency range from 2 to 2.9 GHz, which is about 40% of the central frequency

CONCLUSIONS

The work carried out to develop a water dummy load made it possible to create a relatively simple and inexpensive device with performance characteristics no worse than those of similar foreign commercial devices [7, 8]. The use of the load during the development of the operating modes of a magnetron generator at 2.45 GHz with water cooling made it possible to confirm the efficiency of its cooling system and outline the stages of transition to a continuous operating mode of the microwave generator. The developed load is planned to be used as part of a complex of an atmospheric pressure microwave plasmatron.

REFERENCES

1. D. Li, L. Zhao, F. Lin. Design of C band high power Teflon water load // *IOP Conf. Series: Materials and Engineering*, 2020, v. 717, p. 012002; https:// doi.org/0.1088/1757899X/1717/1/
2. M.A. Panahi, S.A. Ramezani, G.E. Arbakami, and R. Safian. An efficient high power RF dummy load // *IEEE Microwave Wireless Components Letters*. 2015, v. 25, № 6, p. 409-414.
3. E. Eves and V. Yakovlev. Analyses of operational regimes of a high power water load // *Journal of Microwave Power and Electromagnetic Energy*. 2002, v. 37, № 3, p. 127-144.
4. Y.J. Kim, J. Kim, S.J. Wang. Simulation and RF test results on high power water load for KSTAR LHCD system // *Transactions of the Korean Society Spring Meeting Gwangin, Korea*, May 30-31, 2023.
5. J. Zhou, X. Rao, X. Liu, et al. Temperature dependents optical and dielectric properties of liquid water studies terahertz time-domain spectroscopy // *Cite as: AIP Advances 9, 035346 (2019);* doi: 1063/1.5082841
6. M.V. Dixit, Y.M. Jain, A.R. Jadhav, et al. Design a 500 kW CW water load at 3.7 GHz for the LHCD system of SST-1 tokamak // *Fusion Engineering and Design*. 2017, v. 121, p. 32-38; https://doi.org/10.1016/j.fusengdes.2017.05.096
7. https;//www.megaind.com > assets > catalogs
8. https://www.ispecc.com/equipment/microwave-systems-and-components/microwave-components

Article received 25.09.2024

ЕФЕКТИВНЕ ВОДЯНЕ НАВАНТАЖЕННЯ ПІДВИЩЕНОЇ ПОТУЖНОСТІ НА ЧАСТОТУ 2,45 ГГц

А.Г. Нагорний, С.О. Єрьомін, В.А. Батурін, Д.А. Нагорний

Описано водяне узгоджене навантаження, розроблене як елемент апаратури у складі надвисокочастотного плазмотрона атмосферного тиску, що працює на частоті (2450±50) МГц. Навантаження створено з використанням прямокутного хвилеводу перетином 90х45 мм. Моделювання, виконане за допомогою програми CST Microwave Studio, показало, що обрана конструкція забезпечує зворотний відбиток на рівні -42 дБ на частоті 2,45 ГГц. У смузі частот від 2 до 2,9 ГГц навантаження забезпечує коефіцієнт стоячої хвилі за напругою (КСВН) не гірше за 1,2. Досліджено вплив змін температури та солоності води на характеристики пристрою. Навантаження виготовлене та успішно використовується у складі експериментальних хвилеводних трактів.