Experimental Demonstration of the Effect of Groove Shape on the Wave Properties of the Helical Groove Waveguide

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***Abstract*—This letter presents a simple and general fabrication method for helical groove waveguides (HGWs) with successful fabrication of a number of novel HGWs such as the hole-gap-shaped groove HGW, the swallow-tailed groove one, the trapezoid groove one and the ridge-loaded rectangular one. Also, the measurements on these structures have been carried out to determine the dispersion properties of them. The experimental results agree well with the theoretical results and demonstrate a large influence of the groove shape on the dispersion characteristics of the structures.**

***Index Terms*—Gyro-TWT, high power, millimeter wave traveling wave tube, novel helical groove waveguides.**

I. Introduction

A HELICAL groove waveguide (HGW) [1]–[6] is characterized by its much higher power capability, and can be used as a high power microwave and millimeter wave source for applications ranging from satellite communication, airborne imaging radar to electronic confrontation. It is a potential beam-wave interaction structure to be employed in both slow-wave and fast wave regimes, with the advantages of large transverse size, good heat dissipation capabilities, high precision of manufacturing and assembling, robust in construction and low cost. The initial HGW is the helical waveguide of rectangular cross-section which can be considered as a modified disk-loaded cavity waveguide where the adjacent cavities are connected helically. Thus, the electromagnetic wave would propagate around the helical groove path, and is then slowed down in the z-direction, resulting in a wave amplification with an axially traveling electron beam; Meanwhile, it is a naturally more dispersive structure similar to the disk-loaded cavity waveguide, having the properties much like those of the fast wave gyro-TWT [7]. Indeed, it is a surprising structure, and considerable attempts have been made to understand and develop this kind of traveling wave tube.

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Furthermore, there is an increasing interest in helical groove waveguides with various shape of the groove for normal TWTs and gyro-TWTs due to its attractive peculiarity in recent years [3]–[11]. The authors have also given an approach of analyzing arbitrarily shaped helical groove waveguides [5], however, this work mainly concerns about the theoretical analysis. So, it is of much interest and importance to investigate this effect experimentally.

In general, the fabrication of the helical groove waveguide with rectangular or swallowed-tail-shape cross section can be made directly from a solid brass. Nwachuku [12] ever employed this method to fabricate rectangular groove HGW, however, when the groove shape is complex, especially when the width of groove at the mouth is big than that at the bottom, the method becomes invalid. Raytheon Company has already fabricated the ridge-loaded HGW in the initial helical groove TWT, while, their fabrication method isn't reported [1].

In this letter, first, will be presented a simple and general fabrication method for helical groove waveguides with different groove profiles based upon Nwachuku. Using this method, a number of novel HGWs such as the hole-gap-shaped groove HGW, the swallow-tailed groove one, the trapezoid groove one and the ridge-loaded rectangular one have been successfully fabricated. Then, the experimental study along with the simulated results are discussed to ascertain the effect of the groove shape on the dispersion characteristics.

II. Designs and Fabrication

Based on our calculation [13], we have figured out the physical dimensions of a helical rectangular groove waveguide with center frequency of 10 GHz, then obtained the dimensions of other four novel helical groove ones, by just varying the shape of the groove while fixing the outer radius, inner radius and the length of pitch. Fig. 1 shows the profiles and dimensions of these five-type of grooves. Here, the inner radius is 1.25 cm, the outer radius 1.8 cm and the length of pitch 0.6 cm, respectively.

The fabrication method is illustrated in Fig. 2. First, the profile of the groove (for example: the hole-gap shape, shown in Fig. 2) is cut into two parts (Part A and Part B) at position corresponding to the maximum width of the groove R_m. Here, Ri and Ro are the inner radius and outer radius of the groove, respectively. Then, a metal rod with the outer radius R_m is made, and an A-shaped groove is cut helically around it. Subsequently, a B-shaped groove is cut spirally on the inner wall of a cylindrical waveguide with radius R_m. Finally, This cylindrical waveguide

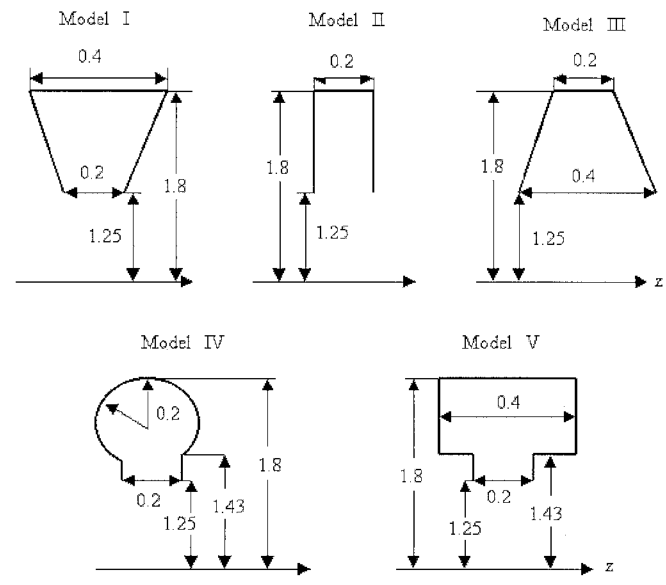

Fig. 1. Profiles and physical dimensions of five-type of grooves (I. swallow-tail, II. rectangular, III. trapezoid, IV. hole-gap-shape, and V. ridge-loaded rectangular; unit: cm).

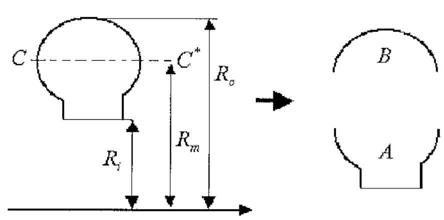

Fig. 2. Illustration of the fabrication method.

is welded to the modified rod, and the center part is eroded away, giving the helical-groove waveguide with a complex profile of the groove.

Fig. 3 shows the photo of the finished helical groove waveguides (From left: The ridge-loaded helical groove waveguide, rectangular one, the swallow-tailed one, the hole-gap-shaped one and the helical trapezoid groove waveguide) with a length of 7.2 cm (model V) or 6.6 cm (other models).

III. Measurements and Discussion

The resonance method [14] is used here to determine the dispersion characteristics. The procedure is to locate the resonance frequencies of a short-circuited structure with the length of several periods. When the phase shift per period satisfies the following relation, a resonance is obtained

$$\beta_0 = \frac{m_0}{N}\frac{\pi}{L}$$

where, β_0 is the fundamental phase change constant, L is the length of the period, N is the number of the period, and m_0 is an integer between 1 and N.

The experimental setup based on the above measurement principle, as shown in Fig. 4, includes 1) shorted helical groove resonance cavity, 2) a network analyzer, 3) coaxial cables, and 4) two coaxial SMA transformers. A network analyzer is used

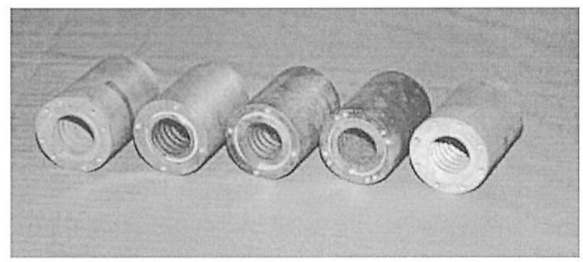

Fig. 3. Photo of five helical groove waveguides.

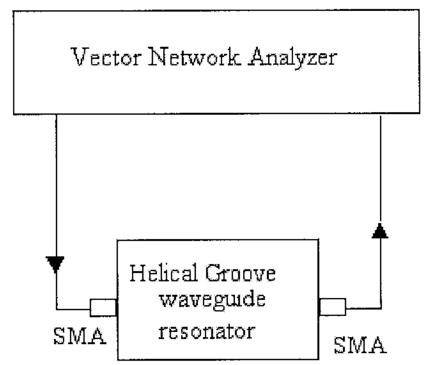

Fig. 4. Sketch of the experimental setup to measure the dispersion characteristics of helical-groove structures.

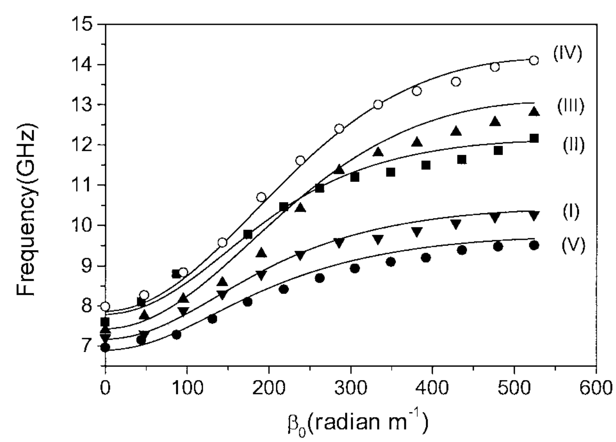

Fig. 5. The dispersion characteristics of the helical groove waveguides with different groove profiles (I. swallow-tail, II. rectangular, III. trapezoid, IV. hole-gap-shape, and V. ridge-loaded rectangular).

to determine the resonance frequency of the transmitted signal through the helical-groove resonance cavity at different phase shift, giving the relation between frequency and phase shift (dispersion characteristics).

The cold experimental results of the dispersion properties of theses helical groove waveguides are shown in Fig. 5. The points with different shapes represent the experimental results of different structures, and the continuous curves show the theoretical results obtained by the theory [5]. They are all in good agreement. And it is clear that the frequency of propagating wave changes with the profiles of the groove at certain phase shift and the difference becomes large with the increase of the phase shift. The results clearly show that the effect of different shapes of the groove on the dispersion characteristics is large, which, therefore, would cause much influence on the performance characteristics of this kind of devices.

IV. Conclusion

In this paper, we have presented the experimental study on helical groove waveguides with different groove profiles, after fabricating them by using a simple and general machined method to investigate the influence of the groove shape on wave properties. The experimental and theoretical results for all the structures are in agreement and demonstrate the large influence of the groove profile on dispersion characteristics.

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