Inner Profile Measurement of Weakly Tapered Open Resonator

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***Abstract*–The three section gyrotron resonator has been fabricated using a single piece of brass and OFHC copper material. The resonator consists of a down taper section, uniform middle section and up taper section with input and output taper angles, 2º and 3º, respectively. To realize the resonator design through fabrication, the inner profile measurement of the weakly tapered open resonator is the foremost important. Therefore, the paper reports the destructive and non-destructive measurement technique to measure inner profile of the resonator. Further, based on the measurement and predicted output power through simulation will help to determine whether the fabricated resonators excite the desire mode and the desire output power**.

***Keywords*: Gyrotron, Weakly tapered resonator, Destructive method, Non-destructive method, Mechanical profiler**

I. INTRODUCTION

Gyrotron oscillators are high-power sources which can produce coherent cyclotron radiation in the millimeter and sub millimeter regions [1]. A 42GHz, 200kW CW gyrotron is under process of development for electron cyclotron resonance plasma heating at IPR, India [2-3].In general, a resonator is a metallic enclosure that confines the electromagnetic waves having several propagating modes. These modes correspond to solution of Maxwell's equations for particular resonator. The resonator has a definite cut off frequency for each allow mode [4]. The resonator of gyrotron is most responsible sub-assembly where the beam-wave interaction takes place to transfer the energy of gyrating electron beam to the transverse electric mode of the RF wave. The mode selection is carefully studied with the aim of minimizing the mode competition, restricting the excitation of undesirable modes in the resonator and to obtain the desired output power. The GCAVSYN code and MAGIC software have been used to synthesize resonator geometry and for selection of mode [5-6]. TE_{03} has been selected as the operating mode for 42 GHz gyrotron. The gyrotron interaction resonator is an open-ended circular resonator including a non-tapered mid-section bounded between two taper sections, namely, down taper and up taper. The down taper and up taper angles are 2^0 and 3^0, respectively. The sensitivity analysis shows that the inner dimensions are very critical with respect to the operating frequency and the output power [3].Fabrication and measurement of the fabricated tapered open resonator due to small taper angles. Thus, the paper reports the measurement technique to measure inner profile of the resonator and to realize whether the fabricated resonator will perform according to the design ones.

II. STRUCTURE OF GYROTRON RESONATOR

The dimension of the 42 GHz, 200 kW gyrotron resonator structure has been finalized through eigenmode and beam-wave interaction simulation and the engineering drawing is shown in figure 1. Based upon the design analysis and engineering drawing, the OFHC copper and brass resonators are fabricated using CNC. The fabricated resonators are shown in figure 2.

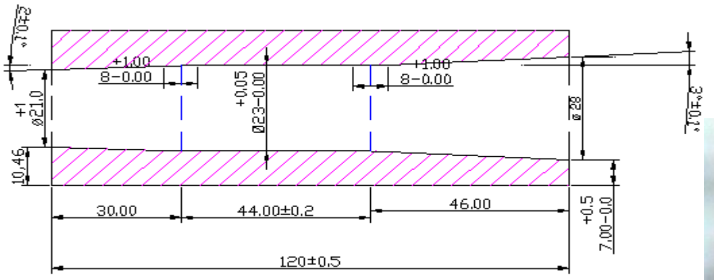
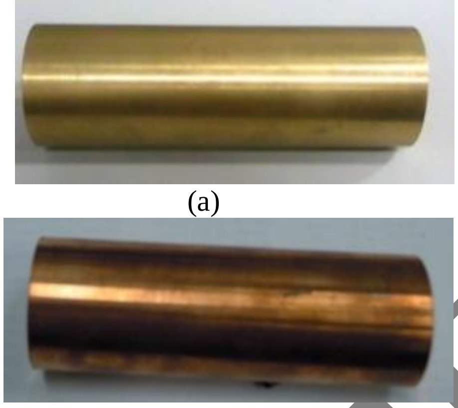


Fig1. Engineering drawing of 42GHz, 200kW Cavity of gyrotron. (All dimensions are in mm).



(a)

(b)

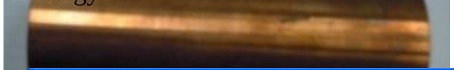
Fig2. Fabricated (a) Brass and (b) OFHC copper resonator of 42 GHz, 200 kW gyrotron.

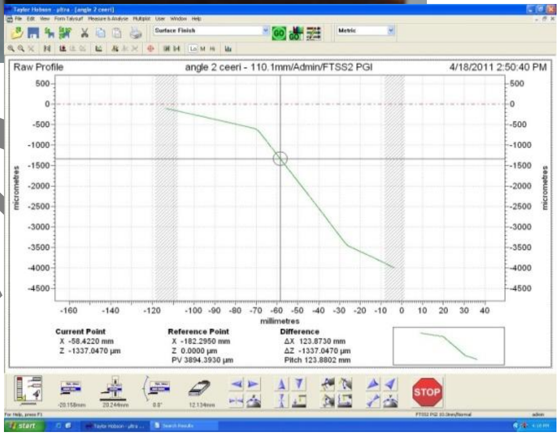
III. MEASUREMENT METHODS

There are three important dimensions of the resonator i.e. each section length, radius and taper angles. For the measurement of above mentioned dimension of the gyrotron resonator, two methods have been adopted i.e. destructive method and non destructive method. The surface roughness of resonator is also measured using SUTRONIC3. The measured surface roughness is in few microns.

A. *DESTRUCTIVE METHOD*

Fig 3. (a) Cut view of brass cavity of 42 GHz 200 kW gyrotron





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Current Point
X -58.4220 mm
Z -1337.0470 µm

Reference Point
X -182.2950 mm
Z 0.0000 µm
PV 3894.3930 µm

Difference
ΔX 123.8730 mm
ΔZ -1337.0470 µm
Pitch 123.8802 mm

Fig3.(b) measured Copper inner cavity profile using mechanical profiler

In the destructive method, the resonator is cut longitudinally into two equal pieces as shown in figure 3(a). The taper angles measurement have been carried out on both pieces using a Dial Bevel Protector with least count 0.05 mm, a Large Tools Makers Microscope with least count 0.01 mm and a mechanical profiler instruments. Tables.1 and 2 show the measured value of the taper angles for brass and OFHC copper cavity using the Dial Bevel Protector and the Large Tools Makers Microscope. The mechanical profiler consists of a probe, which touches the inner surface of the resonator and the complete profile is measured as shown in figure 3(b). By analyzing the profile, the length of each section, up taper and down taper angle and radius at any point are determined. The measured values are given in tables 3 to 5 and these values are in the desired dimensions range with tolerances.

Table 1. List of reading obtained from Dial Bevel Protector

Type of Cavity	Up taper Angle	Down taper Angle
Brass	3.2^0	1.4^0
OFHC Copper	3.2^0	2.2^0

Table 2. List of reading obtained from Large tool makers microscope.

Type of Cavity	Up taper Angle	Down taper Angle
Brass	$3^0 20' = 3.3^0$	$1^0 33' = 1.55^0$
OFHC Copper	$3^0 15' = 3.25^0$	$2^0 10' = 2.16^0$

Table 3. Reading of radius using mechanical profiler

S. No	Radius	Theoretical value (mm)	Measured value (mm)
1	R1	10.5	10.47
2	R2	11.57	11.56
3	R3	14	14.01

Table4. Reading of taper angles using mechanical profiler

S.No	Angle	Theoretical value	Measured value
1	θ1	2°	2.04°
2	θ2	0°	0°
3	θ3	3°	3.04°

Table5. Reading of length using mechanical profiler

S.No	Length	Theoretical (mm)	Measure (mm)
1	L1	30.00	30.06
2	L2	44.00	44.00
3	L3	46.00	46.04

B. NON-DESTRUCTIVE METHOD

Different types of non-destructive methods of measurement have been adopted for the closed interaction resonator. Initially, inside caliper and vernier caliper are used for the measurement of inside diameter at different depths and values are listed in table 6. The input taper and output taper angle are calculated from the measured values using equations (1) and (2), respectively. The values obtained are within the design limit

Table6. Measurement using inside caliper and vernier Caliper

S.No.	Diameter from down taper section (mm)	Diameter of middle section (mm)	Diameter of up taper section (mm)
1.	21.35	23.24	23.34
2.	21.68	23.24	23.77
3.	21.93	23.24	25.08
4.	22.36	23.24	26.48
5.	22.95	23.24	27.66
6.	23.06	23.29	28.00
7.	23.24	23.34	28.25

$$\tan\theta_1 = \frac{\text{Higher side radius} - \text{Lower side radius}}{\text{Length between radius}}$$

$$= \frac{11.62 - 10.67}{30} = 0.031666 \Rightarrow \theta_1 = 1.81^0 \qquad (1)$$

$$\tan\theta_2 = \frac{\text{Higher side radius} - \text{Lower side radius}}{\text{Length between radius}}$$

$$= \frac{14.125 - 11.64}{46} = 0.0540217 \Rightarrow \theta_2 = 3.07^0 \qquad (2)$$

Further, the inner profile is measured using another instrument called vertical CNC with probe as shown in figure 5. The probe used to measure distance and radius of the resonator at different position, which are listed in tables 7 and 8. Using the data, the input and output taper angles are calculated. The calculated input and output taper angles are 2.01° and 3.05°, respectively. The measured values are within the desired dimension with tolerances.

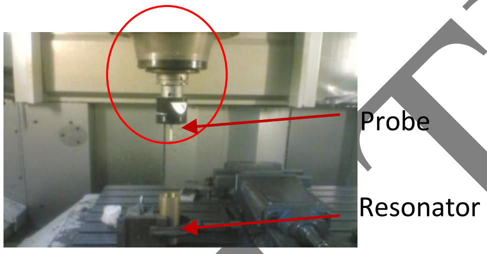

Fig5. Shows the vertical CNC with probe

Table7. Reading of distance and radius for input taper section

S.No	Distance	Z(mm)	R Measured (mm)	R Theoretical (mm)
1	5	174.436	10.5626	10.68
2	10	169.436	10.7365	10.87
3	15	164.436	10.9125	11.04
4	20	159.436	11.0887	11.25
5	25	154.436	11.2648	11.39
6	30	149.436	11.3058	11.57

Table8. Reading of distance and radius for output taper section

S.No	Distance	Z(mm)	R Measured (mm)	R Theoretical (mm)
1	10	173.9275	13.5129	13.45
2	15	168.9275	13.2146	13.19
3	20	163.9275	13.0411	12.93
4	25	158.9275	12.7955	12.67
5	30	153.9275	12.5688	12.41
6	35	148.9275	12.1622	12.15
7	40	143.9275	11.9921	11.89
8	45	138.9275	11.2901	11.63

IV. RESULTS AND DISCUSSION

The measured inner dimensional values of the 42 GHz, 200 kW gyrotron resonator using destructive and non-destructive methods are within the design tolerance [7]. Table 9 shows the comparison of simulated results of output power and resonant frequency for the design resonator and fabricated single piece resonator of OFHC copper and brass. Further, cold characterization of resonator is also performed using free space method and Agilent's PNA. The comparison of simulated and experimental results is presented in table 10. The comparisons of simulated and experimental results of the cold characterization are in good agreement

Table9. Comparison of simulated frequency and power

Type	Angle θ_1	Angle θ_2	Simulated Frequency (GHz)	Simulated Power (kW)
Theoretical	2˚	3˚	42.00	280
OFHC copper	1.95˚	3.09˚	41.90	274
Brass	1.97˚	3.50˚	41.10	196

Table10. Comparison of cold cavity analysis between

simulated and experimental results.

Material	Simulated results		Experimental results	
	Frequency (GHz)	Quality factor	Frequency (GHz)	Quality factor
Brass	42.043	950	42.66	974.25
OFHC copper	42.043	1157	41.95	1112.4

V. CONCLUSION

The inner dimensions of the single piece brass and OFHC copper weakly tapered resonator is determined using different types of destructive and non-destructive methods. The fabricated resonators are within the tolerance value and cold cavity analysis shows that the resonator will perform within the desire limit.

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