The Study of the magnetic modes and Quality Factor in the Gyrotron Tube

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Abstract

This paper involves the study of quality factor as a function of (D/L), where D is the cavity diameter and L is the cavity length (cm unit) of cylindrical cavity in gyrotron tube. In this study we designed MODE_2 for calculating the quality factor of the $TM_{mn\ell}$ modes for $\ell > 0$.

Keywords: Gyrotron Tube, Quality Factor**,** TM modes.

دراسة الأنماط المغناطيسية وعامل الجودة في إنبوب الجايروترون

الخلاصة

تضمن هذا البحث دراسة عامل الجودة (Q) كدالة لابعاد التجويف الاسطوانى(D/L) لانبوب الجايروترون حيث D قطر التجويف و L طوله (بوحدات cm). ومن خلال تلك الدراسة ، تم تصميم برنامج MODE_2 لحساب عامل الجودة (Q) للانماط المغناطيسية $TM_{mn\ell}$ لـ $\ell > 0$.

1- Introduction

The high power capability of gyrotron makes them attractive sources in the millimeter wave range [1]. The gyrotron oscillator is a high power high frequency coherent radiation source in which the magnetron injection gun produces an annular electron beam,the beam is transported to the interaction cavity.a cavity resonator stores energy in the electric and magnetic fields for any particular mode pattern ,In any practical cavity the walls have afinite conductivity and the resulting power losses causes a decay of the stored energy that called quality factor [2].The gyrotron is sometimes called an electron yclotron resonance maser. The gyrotron mechanism depends upon a known characteristic of an electron moving in a magnetic field, when an electron moves parallel to a magnetic field, the field has no effect on the electron. That is, no force is exerted on the electron. If the electron moves with a velocity (V_o) that is not

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parallel to the magnetic field B, then forces will be applied to the electron by the magnetic field, and the tendency will be for the electron to move in a path in the form of a helix. In all these microwave sources, electrons interact with the Electromagnetic Wave (EM) in a microwave circuit (wave guide or cavity) to form electron bunches. These bunches consist of electrons oscillating in phase. The electron beam bunching arrangement of the magnetic and electric fields [3]. The frequency of motion a round the magnetic field is called the cyclotron frequency is given by $\omega_c = \frac{qB}{m}$, and this frequency is proportional to the magnetic field strength [4]. In gyro devices, the electrons interact resonantly with the electromagnetic wave under the synchronism condition, [1]

$$\omega - K_z V_z - \delta\Omega_c \geq 0 \;\ldots\ldots (1)$$

Where ω is the wave frequency, K_z is the propagation constant, V_z is the electron axial velocity, $\delta$is the cyclotron harmonic number, and Ω_c is the electron cyclotron frequency. If both electric and magnetic fields exist simultaneously, the motion of the electrons depends on the orientation of the two fields.In linear- beam tubes (O-type devices) use a magnetic field whose axis coincides with that of the electron beam together as it ravels the length of field but are not influenced by the magnetic field. When the electric field E and the magnetic field flux density B are at right angle to each other, a magnetic force is exerted on the electron beam. This type of field is called a crossed field. In a crossed-field tube (M-type device), electrons emitted by the cathode are accelerated by the electric field and gain velocity; but the greater their velocity, the more their path is bent by the magnetic field [5].

2- Numerical Method

For the cylindrical cavity resonator, as shown in Fig.(1). we choose cylindrical co-ordinates r,θ, z.

The wave equations are obtained with the aid of Hertz vectors and separation into TE and TM components fields for some of the lower –order $TM_{mnl.}$ We use the method of variable separation to get Bessel's equation with Bessel function $J_m(r)$ as the solution. $J_m(r)$ represents a Bessel function of the first sort, order m and argument r.

Fig.2 shows the approximate form of some low –order Bessel functions for law values of the argument. As may be seen, the look rather likes ordinary trigonometric function, having a periodic character, except that the amplitude and period are not constant. The derivative of the Bessel function $J_m(r)$ is written as $J`_m(r)$, where the prime refers to differentiation with respect to the argument; i.e.

$$J'_m(r) = \frac{d}{dx} J_m(r) \;\ldots\ldots (2)$$

The results were obtained of solving the cylindrical wave equations. The field in a cylindrical cavity for TM waves may be written:[6]

$$\left.\begin{aligned}
E_r &= -\sqrt{\frac{\mu}{\varepsilon}}\, A_0 \,\frac{K_z}{K}\, J'_m(K_c r) \,.\cos m\theta \,.\sin K_z \,.\, e^{jwt} \\
E_\theta &= \sqrt{\frac{\mu}{\varepsilon}}\, A_0 \,\frac{K_z}{K}\frac{J_m(K_c r)}{K_c r} \,.\sin m\theta .\sin K_z\, Z.\, e^{j\omega t} \\
E_z &= \sqrt{\frac{\mu}{\varepsilon}}\, A_o \,\frac{K_c}{K} J'_m(K_c r).\cos m\theta \,.\cos K_z Z \,.\, e^{jwt}
\end{aligned}\right\}$$

(3)

$$H_r = -jA_o Am \frac{J_m(K_c r)}{K_c r} \sin m\theta \cdot \cos K_z Z \cdot e^{j\omega t}$$
$$H_\theta = -jA_o m\, J_m(K_c r) \sin m\theta \cdot \cos K_z Z \cdot e^{j\omega t}$$
$$H_z = 0$$

We have, moreover, assumed n> 0, while m, n and l have the same significance as in the rectangular parallelopiped. Further, x_{mn} is the nth zero of $J_m(k_c r)$ sees Fig.2.

3- Results and discussion

We need to know the roots X_{mn} of $(J_m(r) = 0$ and $J^{'}_m(r)$ =0 to determine the resonance frequencies and quality factors of the TM and TE modes in the resonator.

These roots, i.e the zero of $J_m(r)$ and $J^{'}_m(r)$ For TM_waves. We designed a Fortran program MODE_2 (as shown in Appendix_1) to evaluate the Q- factor.

The Q- factors are given by the equations for the TM-modes [7].

$$Q\frac{\delta}{\lambda} = \frac{\sqrt{x_{mn}^2 + p^2 R^2}}{2\pi(1+R)} \quad \text{for } \ell > 0 \; \ldots \ldots \ldots (4)$$

and

$$Q\frac{\delta}{\lambda} = \frac{x_{mn}}{\pi(2+R)} \quad \text{for } \ell = 0 \; \ldots \ldots \ldots (5)$$

These equations are represented graphically in Fig.(3).where $Q\frac{\delta}{\lambda}$ values are plotted for several TM modes as a function of D/L , Where $R = D/L$ and $P=\ell\pi/2$.

The quantity, $Q\,{}^{\delta}/_{\lambda}$, is commonly tabulated instead of Q, since this quantity is a function of only the mode and shape of the cavity. δ is the skin depth in centimeters in the cavity walls.

The skin depth δ is given by the equation $\delta = \sqrt{\lambda P/120\,\pi\mu}$ (cm), Where: μ is the permeability of the wall material, λ is the free-space wave length in cm, and P is the resistivity of the walls in (ohm· cm).

In Fig.3 the axial eigen mode number ℓ will be fixed at the lowest value (ℓ=1) and it gives the highest quality factor.

In enclosed region of magnetic field between (2.75T-3.5T), the modes competing will increase, therefore, show up behavior similar to modes in those values for the following states: TM22ℓ, 03ℓ, 51ℓ, and also TM13ℓ, 61ℓ, 32ℓ as shown in figs.4(a,b). The magnetic field increase with increase the value of ℓ.

4- Conclusions:

The quality factor is proportional to volume of the cavity and the axial eigen number(l) gives the highest quality factor when l >1. the relation between the applied magnetic field and the cavity dimensions for TM_{mnl} -modes shown behaviour similar to TE_{mnl} -modes that had been study by J. W. Salman [8].

References

[1] Yeh, Y. S., Chang , T. H., Wu ,T. S., "*Comparative analysis of gyrotron backward-wave oscillators operating at different cyclotron harmonics*" Physics of Plasma,Vol.11, No.10, p.4547, 2004.

[2] Singh, R. K. and Jain P. K.,."Ohmic Quality Factor and Efficiency Estimation for a Gyrotron Cavity". int. J. Electrical, Computer and

Systems Engineering, Vol.2, No.3, p.204, 2008.
[3] David M. Dozar, "*Microwave Engineering*" John Willy and Sons Inc. 2005.
[4] Samuel Y. Liao, “*Microwave Devices and Circuits*”, 3rd edition. 1990
[5] John Seeger, “*Microwave Theory Components and Devices*”, 1986
[6] Luma Yaseen Abbas, MSc. thesis, Baghdad University, Baghdad, Iraq, 2001.
[7] Montogemry, C. G., Technique of microwave measurements. Mc Graw Hill,Inc. , 1947.
[8] Salman, J. W., Ph.D. thesis, the university of Mustansiriyah, the college of education. 1997

Appendix 1:

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PROGRAM MODE_2
PARAMETER(IMAX=15,JMAX=15)
OMMON/MES/X(0:IMAX+1,0:JMA
X+1)
OPEN (UNIT=2,FILE='XM.DAT')
OPEN
(UNIT=8,FILE='OUTAM.OUT')
OPEN
(UNIT=1,FILE='DATA1.OUT')
OPEN
(UNIT=3,FILE='DATA2.OUT')
OPEN (UNIT=5,FILE='DIL.OUT')
OPEN
(UNIT=6,FILE='DATA3.OUT')
X(0,1)=2.465
X(1,1)=3.832
X(2,1)=5.136
X(0,2)=5.520
X(3,1)=6.380
X(1,2)=7.016
X(2,2)=8.417
X(4,1)=7.588
X(5,1)=8.772
X(0,3)=8.654
X(3,2)=9.761
X(6,1)=9.936
X(1,3)=10.174
WRITE (6,*)
X(3,1),X(4,1),X(5,1),X(6,1),X(7,1),X(
8,1)
 DO 1 I=1,13
 READ(2,*) M,N
 XMN1=X(M,N)
CCCCCCCCCCCCCCCCCCCCCCCC
CCC CALL Q_factor (M1, N1, XMN1,
FDS1, BD1,    DOL1, QDOL1)
CCCCCCCCCCCCCCCCCCCCCCCC
CCC 1  CONTINUE
   STOP
   END
```

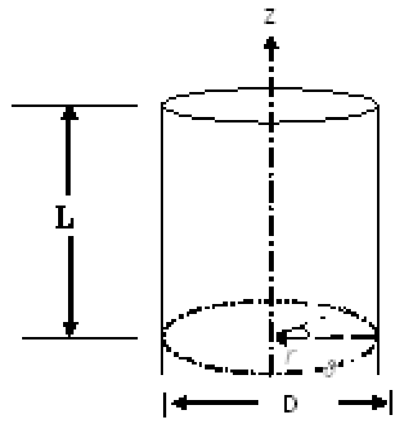

Figure (1) **Show the dimension and cylindrical co-ordinate of cavity resonator.**

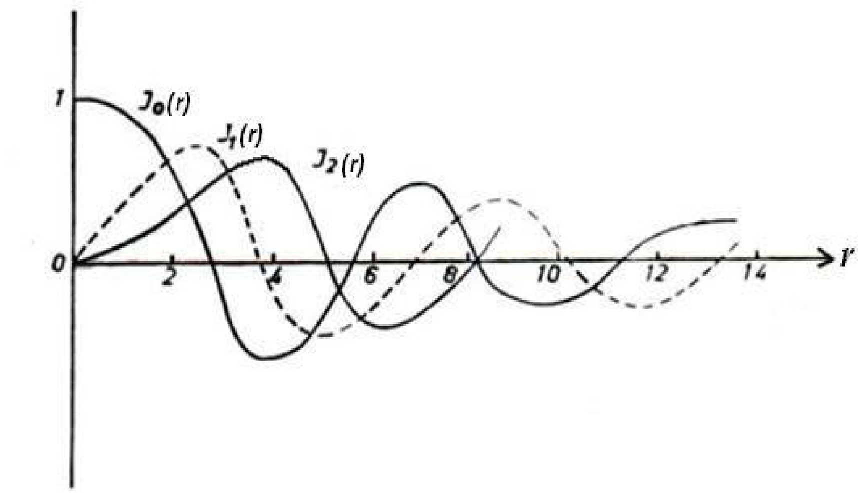

Figure (2) Bessel's functions $J_m(r)$.

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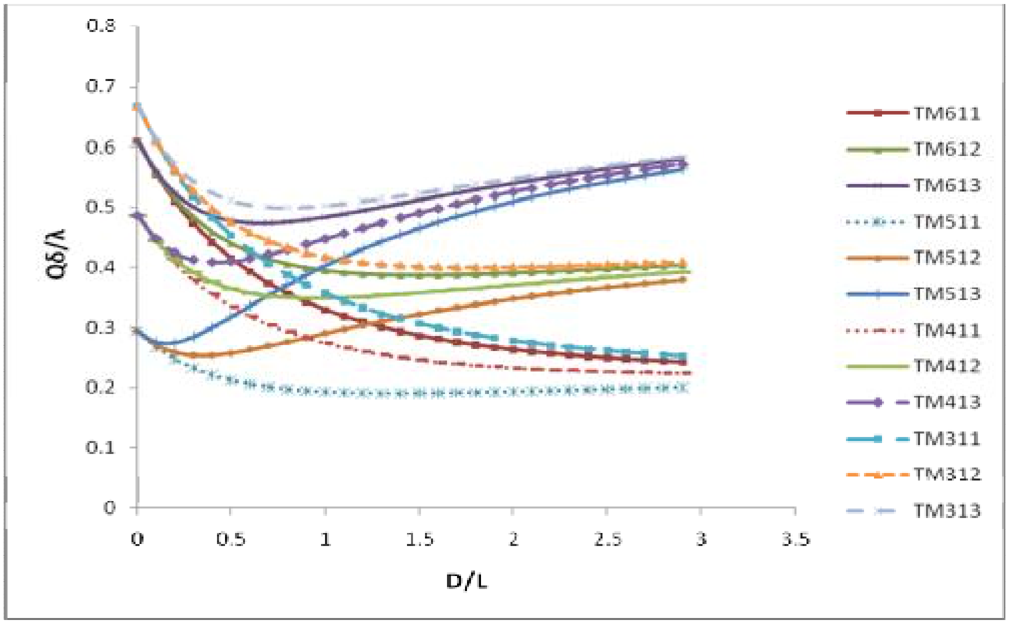

Figure (3) (Qδ/λ) versus (D/L) for several modes in a right circular cylindrical cavity.

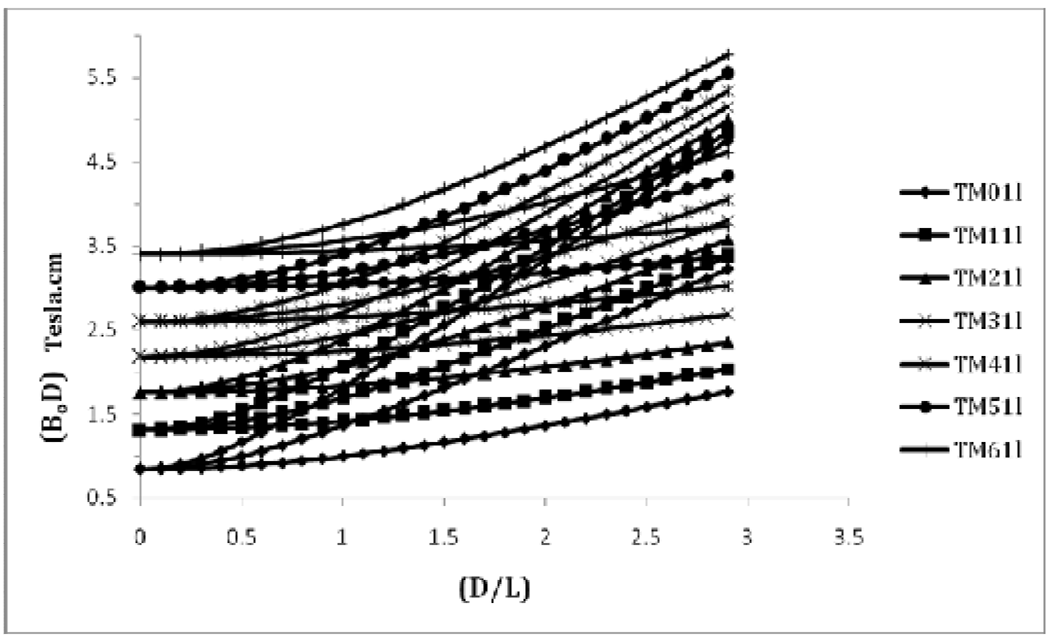

Figure (4a) shows a relation between the applied magnetic field and the cavity dimension for each TM_{mnl}- mode.

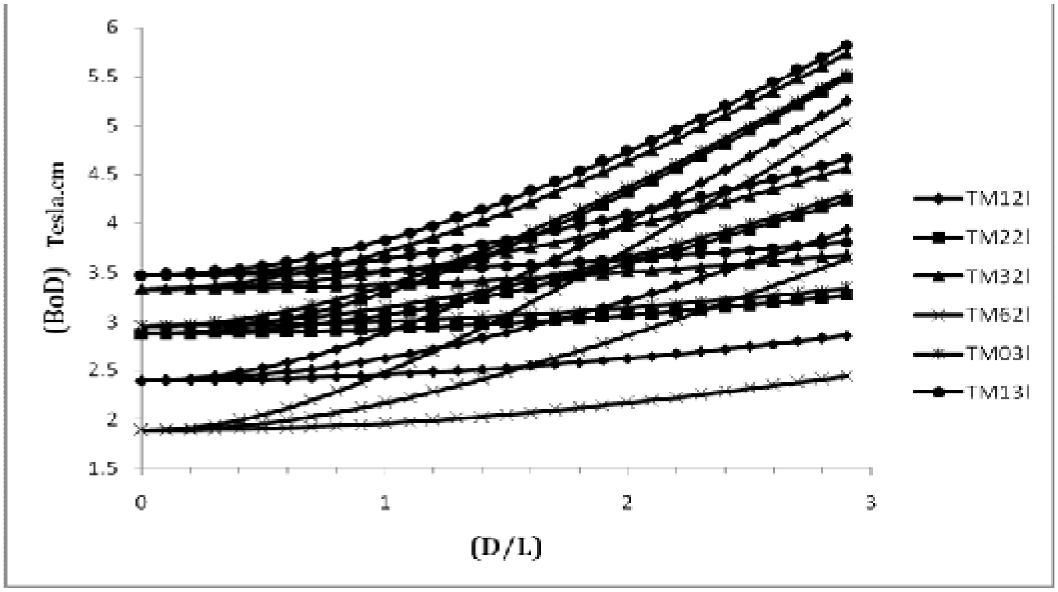

Figure (4b) shows a relation between the applied magnetic field and the cavity dimension for each TM_{mnl}- mode.