Magnetron oscillators

Aim: - ~~proxi~~ To learn the mechanism of microwave oscillation and to derive the cut off voltage equation.

objective: To study the construction of magnetron

* Magnetrons provide Mwave oscillations of very high peak power.

* All magnetrons operated in a dc magnetic field normal to a dc electric field b/w cathode and anode.

* electrons emitted from the cathode are moved in curved paths due to crossed field b/w cathode and anode.

* If the dc magnetic field is strong enough, the electrons will not arrive in the anode, but return to the cathode. Anode current is cut off.

Applications: Peak
                                                                                                                 MW power
                                                                                                                 GHz

i) Radar transmitters with high o/p power

ii) Satellite and missiles for telemetry

iii) Industrial heating   MHz.   (kW)

iv) Microwave ovens.   (915 MHz to 2.4 GHz)   (600 W output power)

Types:-

1. Split- Anode Magnetron
2. Cyclotron- Frequency Magnetron
3. Traveling- Wave magnetron (simply referred as Magnetrons)
   * Cylindrical
   * Linear or planar
   * Coaxial
   * Voltage-tunable

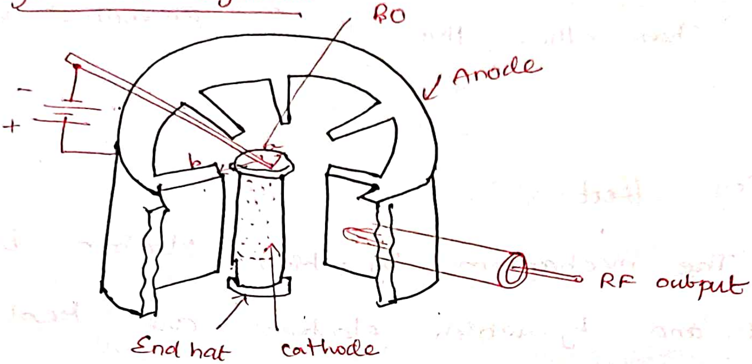
Power output and efficiency:

* peak power o/p upto 40 MW with the voltage of 50 kV at 10 GHz.
  Avg. Power o/p is 800 kW.

* η = 40 to 70%. 2

* commercial use - 3 kW peak power output

① Cylindrical Magnetron

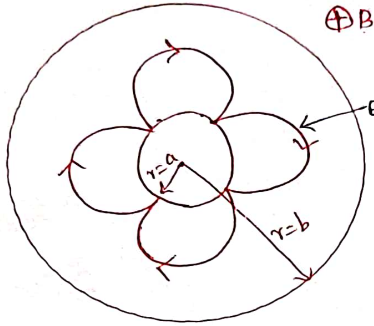


schematic diagram

* uses traveling wave cylindrical magnetron tubes
* Also called conventional magnetron. & consist of a cylindrical cathode radius a surrounded by a cylindrical anode radius b.
* Anode - slow wave structure consisting several reentrant cavities coupled together thro' the anode cathode space by means of slots.
* dc voltage Vo b/w C. & A.
* dc magnetic flux density Bo - z direction by means of a permanent magnet or an electromagnet.
* electrons emitted from cathode try to travel to anode but influence of crossed fields E and H in space b/w anode & cathode, electrons take curved path.

* Accelerated electrons in the curved trajectory, when retarded by the RF field, transfer energy from e- to cavities to grow RF oscillations till the s/m RF losses balances the RF oscillations for stability.

Electron Path in a cylindrical magnetron



electrons experiences force at right angles to their direction of motion

Equations of Electron Motion (or) Hull cut off Voltage

The equations of motion for an electron in a cylindrical magnetron.

$$\frac{d^2r}{dt^2} - r\left(\frac{d\phi}{dt}\right)^2 = \frac{e}{m}E_r - \frac{e}{m} r B_0 \frac{d\phi}{dt} \rightarrow ①$$

$$\frac{1}{r}\frac{d}{dt}\left(r^2 \frac{d\phi}{dt}\right) = \frac{e}{m} B_z \frac{dr}{dt} \rightarrow ②$$

where, $\frac{e}{m}$ = Charge to mass ratio of electron.

$= 1.759 \times 10^{11}$ C/kg

$B_0 = B_z$ is assumed in positive z direction.

$$\frac{d}{dt}\left(r^2 \frac{d\phi}{dt}\right) = \frac{e}{m} B_z \frac{r\,dr}{dt}$$

$$= \frac{1}{2} w_c \frac{d}{dt}(r^2) \rightarrow ③$$

$$\frac{dr^n}{dt} = n r^{n-1} \frac{dr}{dt}$$

$$\frac{dr^2}{dt} = \frac{2r\,dr}{dt}$$

$$\frac{r\,dr}{dt} = \frac{1}{2}\frac{dr^2}{dt}$$

$w_c = \frac{e}{m} B_z$ is the cyclotron angular frequency

By integrating eqn (3)

$$r^2 \frac{d\phi}{dt} = \frac{1}{2} w_c r^2 + \text{constant} \quad \rightarrow (4)$$

At $r = a$, where 'a' is the radius of the cathode cylinder,

and $\frac{d\phi}{dt} = 0$. Eqn (4) becomes

$$0 = \frac{1}{2} w_c r^2 + \text{constant}$$

$$\text{constant} = -\frac{1}{2} w_c a^2 \quad \rightarrow (5)$$

sub (5) in (4)

$$r^2 \frac{d\phi}{dt} = \frac{1}{2} w_c r^2 - \frac{1}{2} w_c a^2$$

$$\frac{d\phi}{dt} = \frac{w_c}{2} - \frac{w_c a^2}{2r^2}$$

The angular velocity of an electron is,

$$\frac{d\phi}{dt} = \frac{w_c}{2}\left[1 - \frac{a^2}{r^2}\right] \quad \rightarrow (6)$$

The electrons move in the direction ⊥r to the magnetic field, the kinetic energy of an electron is given by,

$$\frac{1}{2} m v^2 = eV$$

$$v^2 = \frac{2eV}{m} \quad \rightarrow (7)$$

At $r = b$, where 'b' is the radius from the center of the cathode to the edge of the anode, $V = V_0$ and $\frac{dr}{dt} = 0$, when electrons just graze the anode

Eq. (6) and (7) becomes,

$$\frac{d\phi}{dt} = \frac{\omega_c}{2}\left[1-\frac{a^2}{b^2}\right] \rightarrow (8)$$

$$b^2\left[\frac{d\phi}{dt}\right]^2 = \frac{2eV_0}{m} \rightarrow (9)$$

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Sub. eq. (8) in eq. (9)

$$\left(\frac{d\phi}{dt}\right)^2 b^2 = \frac{2eV_0}{m}$$

$$\frac{2eV_0}{m} = b^2\left[\frac{\omega_c}{2}\left(1-\frac{a^2}{b^2}\right)\right]^2$$

electron acquire tangential as well as a radial velocity.

e^- graze the anode and return toward the cathode → depends on V_0 and B_0.

$$\frac{2eV_0}{m} = \frac{b^2\omega_c^2}{4}\left[1-\frac{a^2}{b^2}\right]^2$$

cyclotron angular freq. $\omega_c = \frac{e}{m}B_{0c}$

$$\frac{2eV_0}{m} = \frac{b^2 e^2 B_{0c}^2}{4m^2}\left[1-\frac{a^2}{b^2}\right]^2$$

$$8V_0\frac{e}{m} = b^2\frac{e^2}{m^2}B_{0c}^2\left[1-\frac{a^2}{b^2}\right]^2$$

B_{0c} - Cutoff magnetic flux density

$$8V_0 = b^2\frac{e}{m}B_{0c}^2\left[1-\frac{a^2}{b^2}\right]^2$$

$$8V_0\frac{m}{e} = b^2 B_{0c}^2\left[1-\frac{a^2}{b^2}\right]^2$$

$$B_{0c}^2 = \frac{8V_0\frac{m}{e}}{b^2\left[1-\frac{a^2}{b^2}\right]^2}$$

Hull cutoff magnetic equation:

$$B_{oc} = \frac{\left(8 V_o \frac{m}{e}\right)^{1/2}}{b\left(1-\frac{a^2}{b^2}\right)}$$

The magnetic field required to return electrons back to cathode just grazing the surface of the anode is → Cutoff magnetic field (or) cutoff magnetic flux density.

If $B_o > B_{oc}$ for a given V_o, the electrons will not reach the anode.

Hull cutoff voltage equation

$$V_{oc} = \frac{e}{8m} B_o^2 b^2 \left(1-\frac{a^2}{b^2}\right)^2$$

If $V_o < V_{oc}$, for a given B_o, the electrons will not reach the anode

Outcome

Able to understand the mechanism of microwave oscillation and analyze the cutoff voltage equations for magnetron.

—x—x—

Strapping :

Strapping is used to avoid mode Jumping in magnetron. Strapping consists of two rings of heavy gauge wire connecting alternate anode poles. These are the poles that should be in phase with each other for π - mode. Phase other than π is prevented by strapping.

Phase focussing effect :

The mechanism by which electron bunches are formed and by which electrons are kept in synchronism with RF field is called Phase focussing effect.