Design of Modulated X-Ray Tube Using Velocity Modulation

M. I. Sanduk

Department of Laser Engineering and Opto-Electronics, College of engineering, Al Nahrain University, Baghdad, Iraq.

Abstract

A theory of new modulated x-ray tube is proposed. The concept of modulation based on velocity modulation technique . The incident electrons are formed as an electrons beam , and by using a bunching cavity , this beam can be modulated . the incident electron bunch will produce a modulated x-ray when strike the target.

Introduction

The modulated x-ray may will have many useful applications in different fields, me **THE TUBE** communication , medicine,....etc. Some of these applications are :

1. The electron beam can be used as a probe in electron probe microscope (EPM) [1] . In using the modulated electron beam the probing will survey different depth. Then one can get three dimensional information .
2. In communication filed, the microwave signal can not pass through plasma or any other medium without interaction , which cause an attenuation [2] . Carrying the microwave signal by x-ray give a good possibility to transmit this signal via any absorbent medium with negligible effect .
3. The microwave ray is easy to be absorbed by wet medium (like living soft tissues , as muscles and fatty tissues). In order to deliver the heating effect of microwave beyond these tissues to hard tissues like bone (that is covered by muscles and fatty tissues) . The modulated x-ray can carry this effect via many layers of these soft tissues .

The ordinary x-ray tube of two electrodes supply continuous and characteristic radiation the intensity of radiation is independent of time .

In 1966 Vainstein and Tsukerman [3] built x-ray tube of three electrodes. One of them was an access to introduce a signal (sinusoidal). The signal was over wide range of frequencies . The detected x-ray was modulated . It was shown that when modulation frequency is chosen properly , sensitivity of recording weak intensities can be increased . In 1980 A.John improved flash x-ray by using the grad-B interaction [4] . Derenzo et. al. proposed a pulsed x-ray system as a measurements technique for florescent life time [5]. In this model the modulation based on using of pulsed laser and photocathode to generate pulsed electrons.

In the present attempt we are going to design a model of modulated x-ray tube. The theory of this new tube follows the modulation technique that can deal with the electron beam ; that modulation technique is the velocity modulation [6] . Accordingly the modified tube can supply a modulated intensity .

The Tube

The intensity of ordinary x-ray radiation is dependant on both of the current and voltage of the electron beam of the tube in addition to the property of the target . For continuous radiation, the continuous intensity is [7]

$$I_{con} = A i_e Z V_o^m \qquad (1)$$

where

I_{con} is the continuous intensity .

A is a proportionality constant .

i_e is the electron current .

Z is the atomic number of the target

V_o is the cathode emission voltage .

m is a constant and approximately equal 2

It is obvious that both of the current and voltage play an important role in the nature of the generated radiation . Therefore this role will be emploied to generate the modulated x-ray

The concept of this new model is depicted in Figure1, unmodulated electron beam pasing through a cavity. When an external A.C. signal applied on the cavety, the electrons will gain or loss energy. In other word a velocity modulation takes place. When the modulated electron beam strike the target, a modulated x-ray will produce.

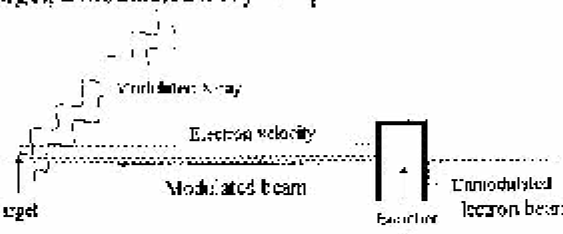

Figure (1): The concept of the modulation technique.

The modulation

The velocity modulation was proposed by Varians Brother [8] to produce microwave , and it was theoretically studied by Webster [9] . The model is for nonrelativestic electrons and , confined by an external magnetic field . The model proposed two consideration ; purely ballistic where no space charage effect and medium-like where processes are controlled by space charge . In the present work we will adopt the cocept of medium like model. Figure 2 shows the general structure of the proposed tube.

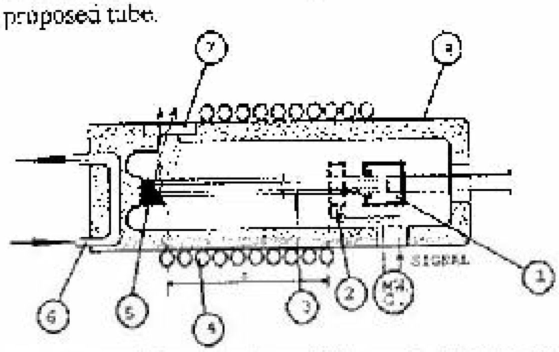

Figure (2): The structure of the modulated x-ray tube. 1-electron gun, 2-cavity, 3-electron beam,4-solenoid magnetic field, 5-target, 6-coolig way, 7-x-ray window, 8-envelop.

The mean steps of its work as follows :

1. It is important to use a magnetic field to construct an electron beam of finite radius (b) and its D.C. current is I_o .
2. Inserting a cavity in the path of the beam, to change the energy of the electrons that pass through it . The cavity is excited by a signal generator . Let the signal like $V = V_1 \sin \omega t$.

The energy of electron after leaving the cavity is :

$$eV = eV_o(1 + A\alpha \sin \omega t) \qquad (2)$$

Where

A : Coupling factor

$\alpha = V_1 / V_o$: excitation ratio

In case of finite radius beam in a metal drift tube , the modulated current along the z axis of the tube is [6] :

$$i(z) \sim i_o \frac{V_1}{2V_o} \frac{\omega}{F\omega_p} \sin \frac{F\omega_p z}{U_o} \qquad (3)$$

Where

F: reduction factor

U_o: DC electron velocity

ω: angular frequency of the signal

ω_p: angular plasma frequency of the electron beam

The angular plasma frequency is related to the DC property of the tube.

3. The electrons that leave the cavity are modulated, and form an accumulation called bunch of electrons. This bunch arises in a certain position far from the cavity . It is the optimum position z_{op} [6]:

$$z_{op} = \frac{\pi U_o}{2\omega_p} \qquad (4)$$

4-The target that produce the radiation should be placed in this position , to receive the bunch of electrons, that have different energies .

5-The generated x-ray will be modulated according to these bunches . If we regard the continuous radiation (eq.1), and by using eqs. 2,3 and 4, the modulated intensity ratio is :

$$\frac{I_{mod}}{I_{con}} = \frac{\alpha}{2} \frac{\omega}{F\omega_p} \sin \frac{F\omega_p z_{op}}{U_o} (1 - A\alpha \sin \omega t)^2 \qquad (5)$$

Where :

I_{mod} : The modified intensity .

I_{con} : The ordinary continuous intensity .

This ratio is controlled by $\alpha, \omega / F\omega_p$. According to eq.5 , Figure 3 shows the modulated intensity of the radiation for electrons of $U_o/c = 0.766$ which is within the limit of classical approximation (For case of $A=1, \omega=2.4\times10^{12}$ rad/s, $V_o=15\times10^4$ V, $U_o= 2.297\times10^8$ m/s, $b=2.126\times10^{-5}$ m, $\omega_p=2.46\times10^{10}$ rad/s, and $F=0.0484$, these values are within the ranges of what are used in x-ray and microwave tubes [6]). A similar result my be obtained in dealing with the problem via the concept of the total energy loss over the time during bremsstrahlung process .

If the carried wave is microwave of frequency of order of 10^9 Hz, whereas x-ray (carrier) frequency of order 10^{14} Hz . So the ratio of timing variation is of order 10^5. This ratio allowed the modulated electron to deliver its energy and produce x-ray before a significant change in the information takes place .

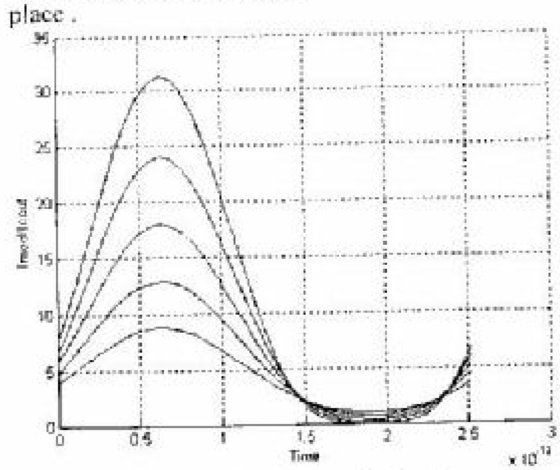

Figure (3): The ratio of the modulated x-ray intensity to the continuous intensity for different values of α, according to eq.5.

Design Consideration

The design parameters of the tube depends on the dreft region z_{op} and the radius b. Eq.4 controls the z_{op} whereas the radius is controlled by the reduction factor F. The relationship between F and the normalized beam radius β ($\beta = \omega b / U_o$) is depicted in Figure 4 [10]. The figure shows various curves of different n, where n is the ratio of tube radius (a) to the beam radius (b). The radius of the unmoculated beam (b) is related to the applied magnetic field (B), where this field is considered as a Brillouin field [11].

$$B^2 = 7\times 10^{-7} (i_o / b^2 \sqrt{V_o}) \quad (6)$$

Where i_o is the D.C. electron current.

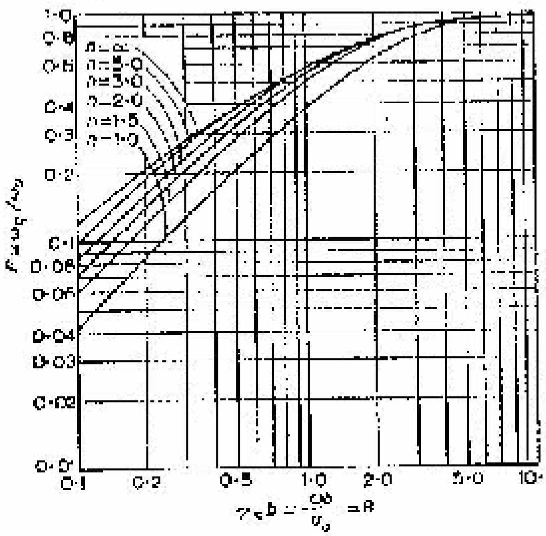

Figure (4): Space charge reduction factors for cylindrical beams in cylindrical tunnel [10].

Conclusion Remarks

1. The ratio of I_{mod} / I_{cwt} is larger than unity for the case of $\omega >> \omega_p$.
2. The minimum x-ray wavelength is (from eq.2):
   $$\lambda_{min} = 12400/V_o (1 + A\alpha \sin \omega t) [A^o] \quad (7)$$
   So the output is a spectrum of different wavelength rays, note Figure 5.
3. The modulated x-ray looks as a pulse train as α increases.

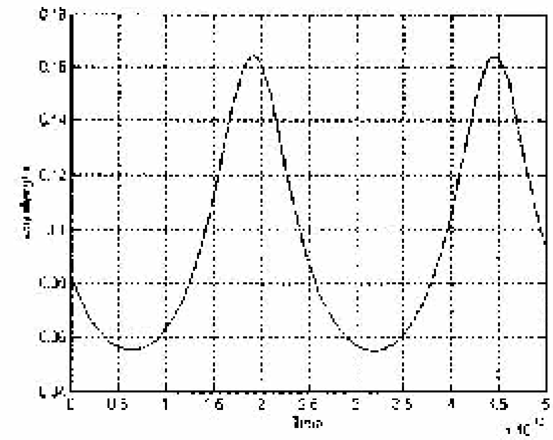

Figure (5): The variation of minimum wavelength (in A°) with the single time, according to eq.7.

References

1. J.I. Goldstein and H. Yakowitz, Practical Scanning Electron Microscopy, Plenum Press, New York (1975).
2. C.B. Wharton, Plasma Diagnostic Techniques ,Edited by R.H. Huddlestor and S.L. Leonard, Academic Press, New York (1965).
3. E. E. Vainshtein and V.G. Tsukerman , Instruments & Experiment Techniques , 4-July-Aug., 915 (1966) .
4. A. John, IEEE Trans Nucl Sci, NS-27, (1980) .
5. S. E. Derenzo, W. W. Moses, and S. C. Blankespoor, IEEE Trans. Nucl. Sci NS-41 (1994).
6. G.D. Sims and I.M. Stephenson , Microwave tube and Semiconductor Devices , Blackie and Son limited , Glasgow (1963) .
7. B.D. Cullity , Elements of x-ray Diffraction , Addison – Wesley, Publishing Company , Inc. USA (1967) .
8. R.H Varian and S.F.Varian , J. Appl. Phys. 10,321 (1939).
9. D.L. Webster , J. Appl. Phys. 10,105 (1939).
10. A. H. Beck, "Space-Charge Waves", Pergamon press, London (1958).
11. J.M. Ghodorow and C. Susskind, "Fundamentals of microwave electronics", Mc Graw-Hill, Inc, (1964).

الخلاصة

تم اقتراح نموذج لأنبوبة الأشعة السينية المحملة. الفكرة التي تم اعتمادها في عملية التحميل هي تقنية تحميل السرعة، وفي هذه الحالة يتم إدخال حزمة الكترونية انفقا على الهدف، و باستخدام فجوة تقوم بتحميل الإشارة على الحزمة الالكترونية تم تحميل السرعة. عند سقوط الحزمة المحملة على الهدف تتولد أشعة سينية محملة.