Theoretical Lecture

Lecture Two

X-Ray Tube

To produce X-ray, the X-ray tube should have all the following equipment (figure1):

1. electron source (cathode),
2. Target to stop the electrons (anode)
3. High voltage supply to accelerate electrons
4. vacuum
5. Tube insert (glass envelope).

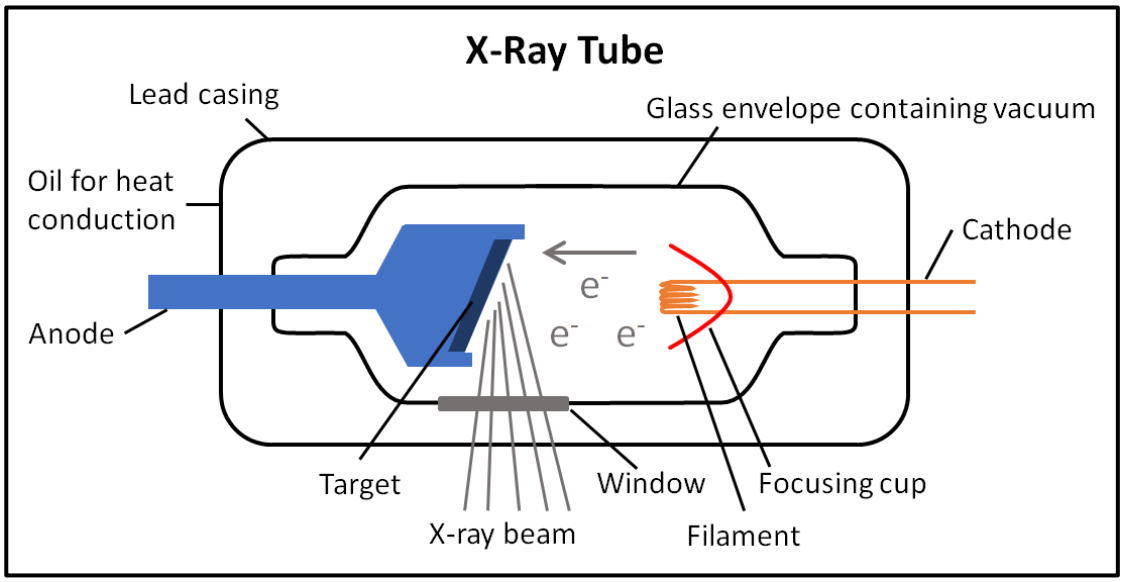

Figure1: the x-ray tube.

1. Cathode (Electron Source):

The cathode is made of tungsten wire in the form of helical filament، surrounded by a focusing cup, the filament is about 0.2 mm in diameter and operates at around 2700 K^o . (Figure 2).

Tungsten is used as filament material because of

- Its high melting point.
- Good ductility (easily drawn into fine wire).

- Tungsten exhibits thermionic emission well below its melting point.

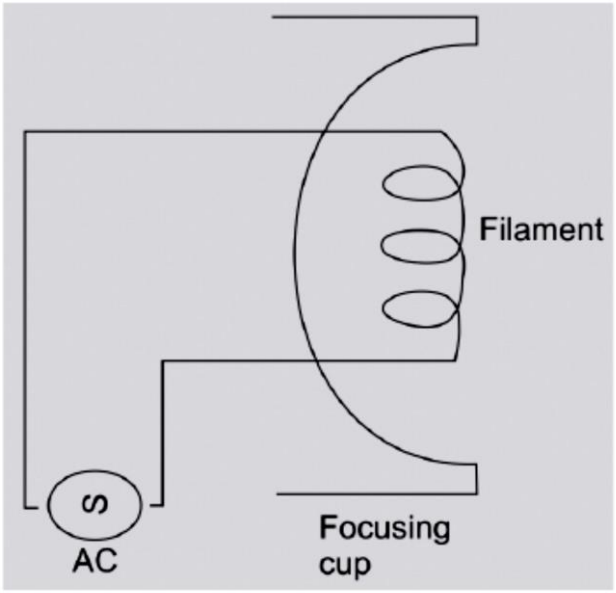

Figure 2: Cathode assembly.

The filament circuit supplies a voltage of 8–12 V and selectable filament current of 3–7 Amp. Electrical resistance to electron flow heats the filament to very high temperature, releasing surface electron through thermionic emission process. The rate of emission depends on the temperature and it can be adjusted by the filament current. The focusing cup controls the width of the electron distribution, and directs the electron toward the target.

2. Anode

The anode is the target electrode, which is maintained at a positive potential (figure 3).

Two types of anode:

- In the stationary anode, the tungsten is a square or rectangular plate of 2 or 3 mm thick and dimension greater than 1 cm.
- Rotating anode design is a solid disk of tungsten with 75–200 mm diameter, with beveled edges.

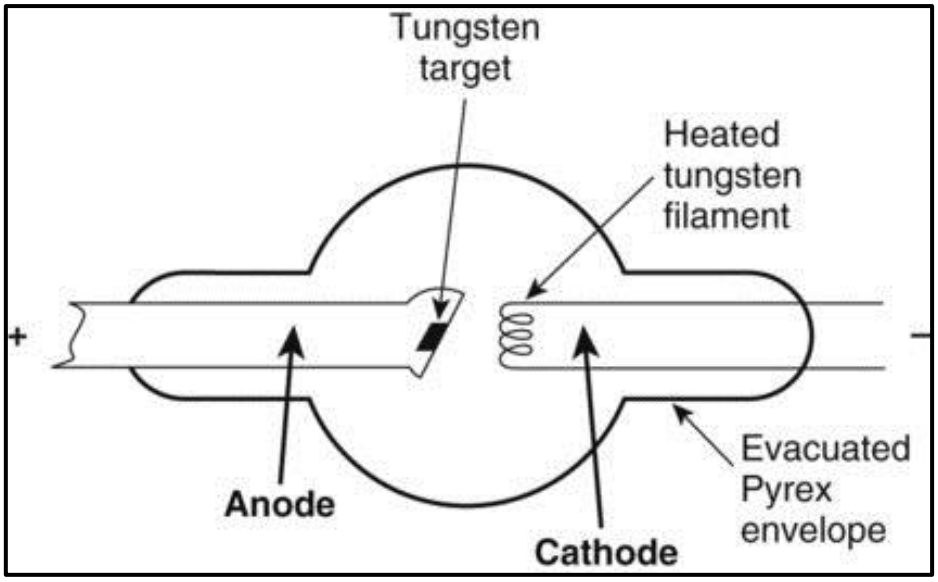

Figure 3:

The target material should possess the following properties:

1. High melting point to withstand high temperature
2. High atomic number to increase the x-ray production efficiency.
3. High thermal conductivity to dissipate heat quickly
4. Easily machined to make smooth surface.

Tungsten is used as a target material, for the following reasons:

1. It has a high atomic number (74) and efficiency of x-ray.
2. It has a high melting point (3400°C) and is thus able to withstand the high temperatures reached by the target during an exposure.
3. It has reasonably good thermal conductivity. This is important as heat must be transferred from the focal areas to the mass of the anode.
4. It has low vapour pressure at high temperature which helps to preserve the vacuum within the insert.

a. Focal Spot Size

Focal spot or focal area: is the area of target with in which the electrons are absorbed and X-rays are generated.

- If the focal area is very small, penumbra will be lesser, and the picture sharpness will be good, but heat removal is difficult.
- If the focal area is large, heat will be removed quickly, penumbra is larger and the picture sharpness is bad.

1. **Actual focal spot size**: is the area on the anode that is struck by electrons.
2. **The effective focal spot size**: is the length and width of the emitted X-ray beam as projected down the central axis of the X-ray tube.

The effective focal spot length is always smaller than the actual focal spot. The relation between them is given as follows:

$$\textbf{Effective focal length} = \textbf{Actual focal length} \times \sin \Theta$$

Where Θ is the anode angle.

The focal spot size is usually expressed in terms of effective focal spot size, which varies from 0.3 mm to 2 mm square.

b. Line Focus Principle

The target of an X-ray tube is mounted at a very steep angle (Θ) with respect to the motion of the incident electrons.

The X-rays will appear to come from a small focal area (effective focus), whereas the electrons bombard relatively a larger focal area (actual focus). Therefore heat is removed very quickly and also the image sharpness is preserved. Figure 4 shows line focus principle.

Example:

Consider the electrons that are made to strike on a target of length **ab**, width **cd** and anode angle **Θ**, then;

Effective focus = actual focus × sin of anode angle

Cd = ab × sin **Θ**

For example, if **Θ** = 17, ab=3 mm, then;

Effective focus = 3 mm × sin 17°

= 3 mm × 0.2924 = 0.877 mm

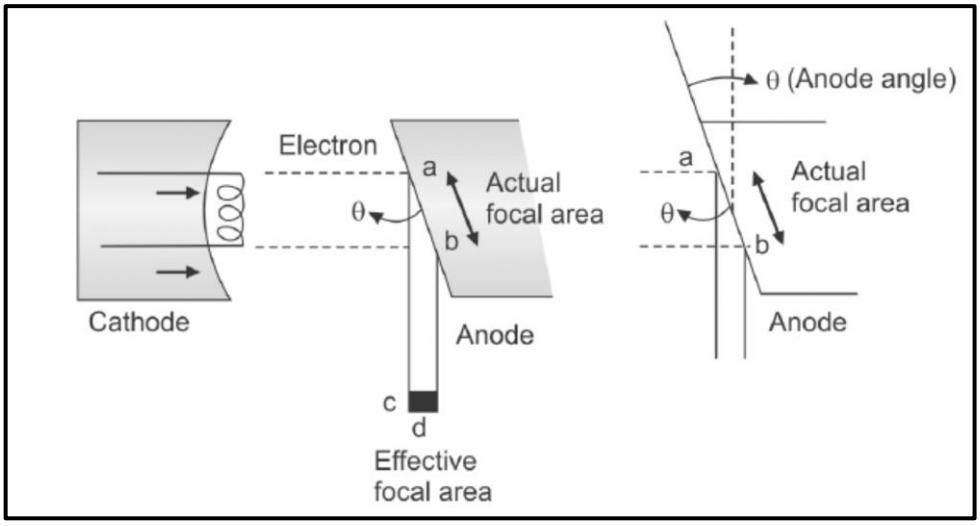

Figure 4: Line focus principle

c. Anode Angle

Anode angle is defined as the angle of the target surface with respect to the central ray in the X-ray field as shown in Figure 4. It has strong relationship with focal spot size and usable X-ray field size.

- A small anode angle gives smaller effective focal spot, but its usable X-ray field is limited.

- Large anode angle gives larger usable X-ray field, but the effective focal spot is larger.
- To optimize the design, larger anode angle with small filament length is used. This will provide smaller effective focal size, with wide field coverage.
- A small anode angle (7–9°) is useful in small field of view (FOV) imaging such as ciniangiography and neuroangiography, where the FOV is limited by image intensifier.
- Modern X-ray tubes are designed with anode angle of 10°–13° with focal spot sizes of 0.6–1.3 mm.

3. The tube insert

The tube insert or envelope is made up of borosilicate glass (Pyrex). The pyrex glass can withstand high temperature and also act as an electrical insulator. It contains vacuum, which support the electrodes.

Properties of the tube insert:

(i) absorbs the X-rays emerging in undesired directions
(ii) maintains the required vacuum
(iii) acts as an electrical insulator
(iv) Also contain the cooling system which removes the heat from the target.

4. Vacuum

A high vacuum is maintained between the anode and cathode. This is necessary to:

(i) avoid the collision between electrons and gas molecules, which gives raise to ionization that reduces the kinetic energy of the electrons
(ii) Prevent oxidation of electrodes
(iii) Act as an electrical insulator.
(iv) The required vacuum is less than 10^{-5} mm Hg.

Questions:

1. List the components of the x-ray tube and explain one of them?
2. Why tungsten used as filament material in cathode?
3. What are the properties that should be available in the target material?
4. Define Actual focal spot size and the effective focal spot size? And what is the relation between them?
5. Explain the tube insert?