Fundamentals of Radio-physics

First Semester

Lecture 3: X-Ray Tabe Heating And Cooling

By

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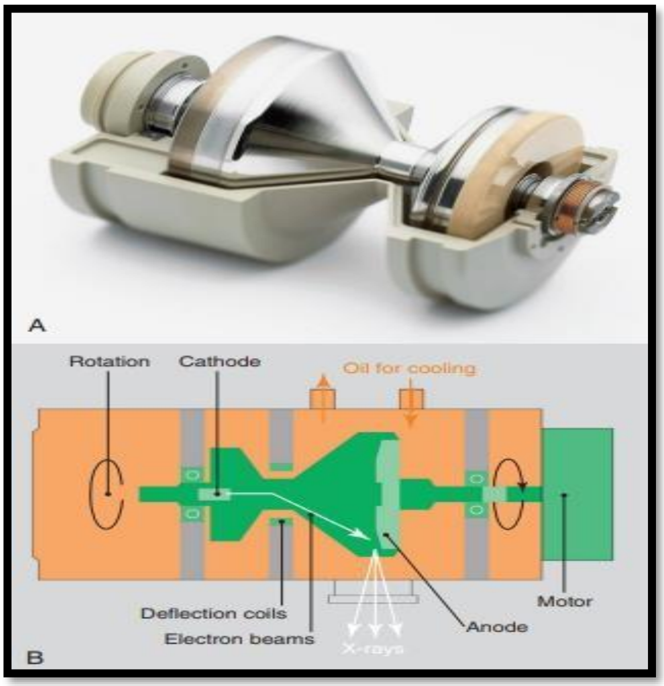
- **The anode** is the target electrode, consists of stator and rotor which is maintained at a positive potential
- **What is the purpose of anode?**

1. Serves as a target surface for the high-voltage electrons
2. The anode is an electrical conductor
3. The anode also must be a good thermal dissipater



This very high capacity x-ray tube revolves in a bath of oil for complete heat dissipation

The electron beam is deflected electromagnetically onto the anode. The cooling oil is in contact with the back of the anode, allowing optimum cooling.

➢ Structure

- Most x-ray tube anodes are made of tungsten
- The high atomic number of tungsten gives more efficient bremsstrahlung production compared to lower atomic number target materials.
- An alloy containing tungsten and rhenium is also used because the addition of 5-10% rhenium prevents grazing of the anode surface.
- The body of the anode is made of materials that are light and have a good heat storage capacity, like molybdenum and graphite.
- Molybdenum is also often used as the target material for anodes used in mammography because it has an intermediate atomic number (Z=42) and the produced characteristic x-rays are of energies suited for this purpose.

➢ Anode types

- **Stationary Anode**

1) Made of tungsten
2) 2-3 mm thick.
3) Embedded in large mass of copper

4) Consist of one filament
5) Triangular/ rectangular shape
6) Anode angle = $15\text{-}20^0$

- **rotating anode** is a small metal disc (usually tungsten or copper)
  that receives the electron beam from the cathode and emits it as X-ray. The anode is positioned at an angle that will direct the X-ray beam into the arc of the C, where the subject of a given scan will be positioned.
- Made of tungsten or alloy of tungsten with Rhenium.
- Has beveled edge
- Angle of bevel is 6 to 20 degrees
- Speed of rotation is 3000rpm practically
- a tungsten disc rotates during an exposure, thus effectively increasing the area bombarded by the electrons
- the energy is dissipated to a much larger volume as it is spread over the anode disc.

Anode Cooling Chart

-The anode has a limited capacity for storing heat. It is possible through prolonged use or multiple exposures to exceed the heat storage capacity of the anode. Through diagrams it is possible:
-Determines the maximum heat capacity of the anode.
-Determines the length of time required for complete cooling following any level of heat input
-Different from the radiographic rating chart, the anode cooling chart **does not depend on** the filament size or the speed of rotation.

-The tube represented in Figure 3 has a maximum anode heat capacity of 350,000 HU. The chart shows that if the maximum heat load were attained, it would take 15 minutes for the anode to cool completely.

-The rate of cooling is rapid at first and slows as the anode cools. In addition to determining the maximum heat capacity of the anode, the anode cooling chart is **used to determine** the length of time required for complete cooling after any level of heat input.

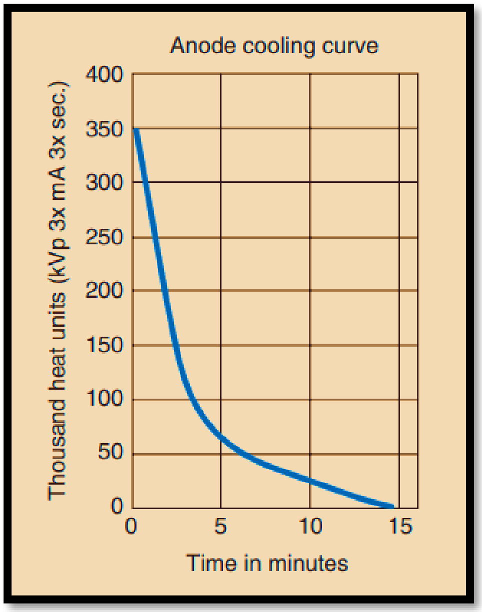


Figure3: Anode cooling chart shows time required for heated anode to cool.

During x-ray production, most of the kinetic energy of the electrons is converted to heat.

This heat can damage the x-ray tube and the anode target.

The amount of heat produced from any given exposure is expressed by the heat unit (HU).

Heat Units (HU) = (Tube voltage) (Tube current) (Time)
= (kVp) (mA) (sec) . Constant

Generator type	Constant
Single Phase 1φ	1
Three Phase 3φ	1.41
High Frequency	1.45

Example: Radiographic examination of the lateral lumbar spine with a single- phase imaging system requires 98 kVp, 120 mAs. How many heat units are generated by this exposure?

HU= 98 kVp ×120mAs ×1= 11760 J

Example: How much heat energy (in joules) is produced during a high-frequency mammographic exposure of 25 kVp, 200 mAs?

HU = 25 kVp × 200 mAs × 1.4= 7000 J

Example: A examination is performed with a high frequency imaging system at 120 kVp and 500 mA 0.7 s. Calculate the length of time necessary for the anode to cool to 50,000 HU after 5 exposures?

For one exposure

HU = 120 kVp ×500mA × 0.7s × 1.45

= 60,900 J

For 5 exposure

HU = 5 × 60,900

= 304,500 J

From the chart (Figure 4), I went to just 50,000 HU which is about 6.25

- # Heat production

- Heat is produced in the focal spot area by the bombarding electrons from the cathode. Since only a small fraction of the electronic energy is converted in x-radiation, it can be ignored in heat calculations. We will assume all of the electron energy is converted into heat. In a single exposure, the quantity of heat produced in the focal spot area is given by
  - **Heat (J) = KV_e * MAS**

or

  - **Heat (J) = w *KV_p * MAS.**
- Where **KV_e** is the <u>effective</u> KV value and **KV_p** is the <u>peak</u> **KV** value

  w is the waveform factor in three-phase, 12 pulse, 0.99; three-phase, 6-pulse, 0.96; single-phase, 0.71.

- **Heat Capacity**

  The heat capacity of the focal spot track is generally the limiting factor for single exposures. In a series of radiographic exposures, CT scanning, or fluoroscopy, the build-up of heat in the anode can become significant. Excessive anode temperature can crack or warp the anode disc.

- **Focal Spot Size**

  -The only advantage of a large focal spot is increased heat capacity.

  -The large focal spot is used when the machine must be operated at power levels that exceed the rated capacity of the small focal spot. The specified size of an x-ray tube focal spot is the dimensions of the effective or projected focal spot

- **Anode Angle**

  - The actual relationship between focal spot width (and heat capacity) and the size of the projected focal spot is determined by the anode angle.

  - the track width and heat capacity are inversely related to anode angle.

  -Although anodes with small angles give maximum heat capacity, they have specific limitations with respect to the area that can be covered by the x-ray beam.

  - X-ray intensity usually drops off significantly toward the anode end because of the heel effect.

Housing Cooling Chart

The cooling chart for the housing of the x-ray tube has a shape similar to that of the anode cooling chart and is used in precisely the same way.

 Based on the quantity of heat units, these charts provided radiographers with information regarding the amount of time that must elapse before initiating another exposure.