APPH 226: The X-ray Tube

Objectives: 1.1-1.3

MRT Program

- "There is nothing magical about the production of x-rays; it is simply the manipulation of electricity"
- Factors selected on the console to produce x-rays are:
  - Volt
    - Kilovolts – unit of measure for electric potential
  - Ampere
    - Milliampere – unit of measure for current

    - Read over Chapter 4 (Bushong) – review concepts

Formation of X-rays

- To produce x-rays, must have:
  - Source of electrons
  - Means to accelerate the electrons
  - Means to decelerate the electrons (target)
  - Vacuum

- All of these conditions are met inside of an x-ray tube

Types of X-ray Tubes

- Wilhelm Rontgen discovered x-rays in 1895
- Rontgen was a mechanical engineer and physicist
- Crookes tube
  - Early tube – used by Wilhelm Roentgen
  - No vacuum, gas filled
  - One mA station
- Coolidge tube
  - Vacuum tube
  - Glass or metal enclosure
  - Various mA stations

Tube Housing

- X-ray tube is contained inside a protective housing
- Must provide solid, stable support
- Lead lined metal structure
  - Serves as electrical insulator and thermal cushion
  - Housing contains cooling oil which helps dissipate heat away from tube
- Two large electrical cables enter the housing and are securely attached to the tube through special high voltage receptacles
- Housing design reduces leakage radiation to acceptable limits

X-Ray Tube

- Relatively large in size:
  - 30-50 cm long
  - 20 cm diameter
- Is a vacuum tube that contains:
  - Cathode
  - Filament
  - Anode

    - All contained within glass/metal envelope

Glass (or metal) Envelope

- Main purpose:
  - Maintain a vacuum within the tube

- Typically made of borosilicate glass
  - Heat resistant
  - Can have discoloration from vaporized tungsten coating inside on glass
    - Can cause arcing and tube failure

Glass (or metal) Envelope

- Metal envelope
  - Maintains constant electric potential between electron stream from cathode and enclosure
  - Avoids arcing problem, extends tube life
  - High capacity tubes

Glass (or metal) Envelope

- Both enclosures have a specially designed exit point for x-rays
  - Port or window
  - Approximately 5 cm^2 in size
- Section of the enclosure that is thinner than the rest
- Allows x-rays to pass through with minimal interference (absorption)

Cathode Assembly

- Negative side of the tube
- Provides the source of electrons required for x-ray production
- Made of two main parts
  - Filament
  - Focusing cup
- Function:
  - To produce or emit electrons

Filament

- Most tubes have two filaments
  - Called dual focus tubes – large and small
- Emits electrons when it is heated
- Typically made of thoriated tungsten
  - 1-2% thorium
    - Increases thermionic emission, extends filament life
  - Tungsten (atomic number 74) has high melting point (3410°C),
    - Doesn't vaporize easily
  - Higher thermionic emission
    - Allows filament to operate at high temperatures required for x-ray production

Filament

- Similar to toaster coil or lightbulb filament, but bigger
- Set inside focusing cup
- Diameter of filament is 1-2 mm
- Length can be 1-2 cm
  - Determines focal spot size
  - Large or small
- Typical to have two filaments parallel to each other and connected to one common ground wire

Function of the Filament

- Provides resistance to the flow of electrons so heat is produced
  - Causes thermionic emission to occur
- This happens as the exposure switch is pushed halfway down and the rotor is activated
- Filament current heats up filament and electrons are boiled off by thermionic emission

Focusing Cup

- Made of metal (often nickel) and surrounds filament on its back and sides
  - Front is open and facing anode
- Negatively charged to force the electrons together into a cloud as they come off the filament – electromagnetic repulsion
- Size, shape and charge of the focusing cup and how filament is situated will affect how well the electrons are 'focused' onto the target
- Without it, electrons would repel and scatter as they come off the filament

Space Charge Effect

- Focusing cup shapes the electrons from filament into a cloud
  - Called space charge
- Self limiting
  - When it reaches the size (set by current used), difficult for additional electrons to be emitted
- This stabilizing, self limiting factor is called the ‘space charge effect’

Focal Spots

- Large filament = large focal spot (0.3 - 2mm)
- Small filament = small focal spot (0.1 - 1 mm)
- Selection made with the mA station selector on the console
  - ~300 mA and under – can select either focal spot
  - ~400 mA and over – only large focal spot is allowed due to heat capacity
- Filament current will heat the appropriate filament as set on the console, not both

Anode Assembly

- Positive end of the tube
- Functions:
  - Electrical conductor
    - Some electrons interact with target to produce x-rays, the rest continue on as current flow through the x-ray circuit
  - Mechanical support for target
    - Target required for electrons to interact with and produce x-rays
  - Thermal dissipater
    - Tremendous amount of heat generated during x-ray production

Anode Design

- Two designs for anodes:
- Stationary
  - Target does not move, embedded into one end of the copper anode
  - Example: dental units
  - Major disadvantage – electrons always hitting same small target area, heat builds up rapidly, limited to small exposures
- Rotating
  - This is used in general purpose rooms today
  - Allows electron beam to interact with a greater target area

Rotating Anode Design

- Consists of:
- Rotating disc made of a tungsten coating over a molybdenum core
  - Alloyed Tungsten adds mechanical strength to withstand the high speed rotation and constant thermal expansion/contraction
- Copper shaft with molybdenum core
  - Copper is used for it's excellent thermal and electrical conductive properties
  - Molybdenum is used for the disc base and shaft core because of its low thermal conductivity and light weight strength
    - Makes anode lighter and easier to rotate

Rotating Anode Design

- Rotation of anode increases the target area ~500 times
- Heat capacity can be improved by increasing the speed of the anode rotation
  - General x-ray tubes are ~3400 rpm
  - High capacity x-ray tubes are ~10000 rpm

Induction Motor

- Anode rotates using an electromagnetic induction motor
- Two major parts are:
  - Stator
    - outside the glass/metal envelope
  - Rotor
    - inside the envelope

Induction Motor

- Stator
  - is made of electromagnetics arranged in pairs around the rotor
  - outside the enclosure
- Rotor
  - is a shaft made of an iron core surrounded by a copper cuff and located in the center of the stator – inside the enclosure

Rotor

- Inside of the rotor between the shaft and copper cuff, contains silver-plated steel ball bearings
  - Helps the rotor to rotate faster
  - Can hear them rotating (sound of the tube)
  - Ball bearings are a high temperature lubricant
  - Worn down bearings can begin to change shape, will hear a grinding sound when rotor is activated and may cause rotor to wobble
    - Decreases tube efficiency

Rotating Anode

- Heat is spread out over a larger surface area
- Electrons strike a small part of anode surface area, and the area changes due to the rotation
  - Becomes a focal 'track'
  - Heat build up over the focal track circumference vs. one spot
- Large increase of the heat load capacity and exposure techniques that can be used

Rotor Mechanism Failure

- If the rotor mechanism fails, this can cause the anode to overheat, resulting in:
  - Pitting
  - Melting
  - Cracking

Exposure Switch

- After the switch is activated, there is a short pause before the exposure is made
- During that pause while the switch is pressed:
  - Rotor is accelerating
  - Filament current is increasing to provide the appropriate x-ray tube current

Putting it all together….

What is required to produce x-rays are:

- Source of electrons (electron cloud)
- Means to accelerate (potential difference)
- Means to decelerate the electrons (anode is ready)
- Vacuum

Putting it all together…

- #1. Technologist will select the desired exposure factors on the console
  - kVp – kilovolt peak
  - mAs – milliampere second

Putting it all together....

- #2. Exposure switch is pressed (half way)
  - Some of the electricity goes to induction motor to bring rotor up to speed ("hitting the rotor")
  - As the rotor is coming up to speed, the selected filament is energized until the electron cloud is built up to the appropriate size
  - This first phase of the exposure lasts about one second

Putting it all together…

- #3. Exposure switch is depressed all the way
  - This is where the x-ray production is actually initialized
  - Actual exposure is measured in ms
  - Voltage from autotransformer (controlled by kVp selected) passes through a rectifier bank and then to the cathode and anode
    - Rectifier is important so that the cathode is always the negative side and the anode is always positive
    - This creates the potential difference between cathode and anode

Putting it all together…

- Electron cloud is attracted to the target because of the large potential difference
  - Filament electrons can reach speeds of half the speed of light in that small gap
- As electrons flow from cathode to anode, this is a continuation of electricity flow through the x-ray circuit
- As target is penetrated by electrons, interactions occur with the tungsten atoms
  - X-rays and heat are produced

Extending Tube Life

- Lifespan of x-ray tube is primarily in the control of the technologist
- Practices that can extend tube life:
  - <u>HEAT</u> is the main factor/cause of tube failure



  - Heat is conducted through the stem of the anode to the rotor to the glass envelope, which raises the temperature of the tube housing and then the surrounding air

Extending Tube Life

- Minimum exposure factors for each exam
  - Smallest exposures possible
- Utilizing faster image receptors
  - Minimizes exposure required
- Warming up anode to prevent thermal shock
  - As part of start up routine

Extending Tube Life

- Use shortest exposure times possible
  - Extended exposure time will keep the anode at high temperature for a long time, passing heat along
  - Rotor bearings can be heated excessively, increasing rotational friction and causing imbalance of the rotor anode assembly
  - Continuous heat to the rotor assembly, oil bath and x-ray tube housing can cause all of these to fail
  - High mA for prolonged exposure causes excessive heating of filament – more tungsten vaporized

Extending Tube Life

- Filament Care
  - Due to high temperature of filament, the tungsten atoms are vaporized and begin to coat the inside of the enclosure
    - Can lead to arcing and tube failure
    - As the tungsten vaporizes, the filament wire becomes thinner and eventually breaks
      - Handle tube with care

Readings

- Bushong: Radiologic Science For Technologists 11th Ed.
  - Pg. 106-113 (end after first paragraph on right column)
  - Pg. 116 (start at X-Ray Tube Failure) -118 (end before Rating Charts)
  - Chapter 4
    - review of electricity, magnetism and electromagnetism concepts – take a quick flip through this chapter to refresh your memory