SAWA UNIVERSITY

تقنيات أجهزة التصوير التقليدية/ الكورس الاول

X-RAY TUBE

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الجانب النظري محاضرة رقم (3)

Theoretical Lecture No. (3)

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(INTRODUCTION)

The X-ray tube is the heart of any radiographic system, responsible for converting electrical energy into X-radiation. It operates under high voltage to accelerate electrons from the cathode to the anode within an evacuated glass or metal envelope. The design of the tube ensures efficient electron acceleration, effective heat management, and controlled X-ray emission to produce diagnostic images while minimizing exposure to both patients and equipment.

(BASIC COMPONENTS OF THE X-RAY TUBE)

The X-ray tube comprises two primary electrodes: the cathode and the anode, enclosed in a vacuum tube and supported within a protective housing. The cathode contains the filament and focusing cup, which control electron emission. The anode, typically made of tungsten, serves as the target for electron bombardment. The interaction between high-speed electrons and the anode material results in X-ray photon production.

(CATHODE ASSEMBLY)

The cathode assembly includes one or two tungsten filaments mounted within a metal focusing cup made of nickel or molybdenum. When heated by the filament current, the tungsten wire emits electrons via **thermionic emission**. The focusing cup shapes and directs the electron stream toward the anode focal spot, ensuring a concentrated electron beam and sharp image resolution.

(FILAMENT FUNCTION AND THERMIONIC EMISSION)

Thermionic emission occurs when the filament is heated to approximately 2200°C, allowing electrons to escape from the tungsten surface. The emitted electrons form a **space charge cloud**, which is controlled by the focusing cup potential. Filament current determines the tube current (mA), influencing the quantity of X-rays produced.

(ANODE ASSEMBLY)

The anode serves as the site for X-ray production and heat dissipation. It consists of a tungsten target embedded in a copper stem for thermal conduction. The anode rotates at high speeds (3,000–10,000 rpm) to spread heat over a larger surface area, prolonging tube life. Stationary anodes are still used in dental and portable units where heat generation is minimal.

(TARGET MATERIAL AND HEAT MANAGEMENT)

Tungsten is used as the target material due to its high atomic number ($Z = 74$), high melting point (3,370°C), and good thermal conductivity. These properties ensure efficient X-ray production and resistance to heat damage. Heat generated from electron bombardment is primarily dissipated by radiation, conduction, and convection.

(X-RAY PRODUCTION MECHANISM)

When high-speed electrons strike the tungsten target, their kinetic energy is converted into electromagnetic radiation through two interactions: **Bremsstrahlung radiation** and **Characteristic radiation**. Bremsstrahlung accounts for the continuous spectrum, while characteristic radiation occurs when electrons eject inner-shell electrons from tungsten atoms, producing photons with discrete energies.

(THE LINE FOCUS PRINCIPLE)

The **line focus principle** is designed to achieve a small effective focal spot while maintaining a large actual focal area to manage heat. By tilting the anode surface (commonly at 12°–17°), the projected effective focal spot becomes smaller than the actual focal spot, improving spatial resolution and reducing image blur.

(FACTORS AFFECTING THE FOCAL SPOT)

The size of the focal spot depends on the filament length and the anode target angle. Smaller anode angles yield smaller effective focal spots but also reduce the field coverage. Therefore, radiographic tube design balances between resolution and field size requirements.

(THE HEEL EFFECT)

The **heel effect** refers to the variation in X-ray intensity along the anode-cathode axis of the beam. X-rays emitted toward the anode side must pass through a greater thickness of tungsten, causing attenuation and reducing beam intensity compared to the cathode side. This results in higher intensity on the cathode side of the beam.

(CLINICAL SIGNIFICANCE OF THE HEEL EFFECT)

The heel effect is exploited clinically by positioning the thicker part of the patient’s anatomy under the cathode side (e.g., chest or abdomen) and the thinner part under the anode side. This compensates for intensity variation and ensures uniform exposure across the image receptor.

(CONTROLLING THE HEEL EFFECT)

The heel effect can be controlled by adjusting the anode angle, source-to-image distance (SID), and field size. Larger anode angles and longer SID reduce intensity variation, while smaller fields minimize noticeable differences.

(TUBE HOUSING AND COOLING SYSTEM)

The entire tube is enclosed in a protective housing that provides radiation shielding, mechanical support, and oil for cooling. Some modern systems use circulating oil or air fans to dissipate heat from the anode and housing, maintaining tube performance and extending life.

(COMMON TUBE FAILURES)

Tube failures often result from filament burnout, anode pitting, or bearing wear. Overheating from repeated high exposures can damage the focal track or cause cracking of the anode disk. Proper warm-up procedures and adherence to tube rating charts prevent such damage.

(SUMMARY)

The X-ray tube's performance depends on precise engineering of its design, focal geometry, and heat management. Understanding the line focus principle and heel effect helps optimize image quality, minimize artifacts, and extend equipment lifespan—key competencies for radiologic technologists.

QUIZ

Q1 (MCQ):WHICH OF THE FOLLOWING STATEMENTS BEST DESCRIBES THE PURPOSE OF TILTING THE ANODE SURFACE IN AN X-RAY TUBE?

A) TO INCREASE ELECTRON EMISSION FROM THE FILAMENT B) TO REDUCE THE SIZE OF THE EFFECTIVE FOCAL SPOT WHILE ALLOWING A LARGE ACTUAL FOCAL AREA

C) TO INCREASE THE HEEL EFFECT INTENSITY D) TO PREVENT ANODE ROTATION

Q2. DESCRIBE THE MAIN COMPONENTS OF THE X-RAY TUBE AND EXPLAIN THE FUNCTION OF EACH IN THE PROCESS OF X-RAY PRODUCTION..

Q3. EXPLAIN HOW THE LINE FOCUS PRINCIPLE IMPROVES BOTH IMAGE RESOLUTION AND TUBE HEAT CAPACITY. PROVIDE AN EXAMPLE OF HOW CHANGING THE ANODE ANGLE AFFECTS THE EFFECTIVE FOCAL SPOT SIZE..

Q4. DISCUSS THE CAUSE OF THE HEEL EFFECT AND HOW IT IMPACTS RADIOGRAPHIC IMAGE QUALITY. HOW CAN A TECHNOLOGIST USE THIS EFFECT ADVANTAGEOUSLY IN CLINICAL IMAGING?.

Q5. A RADIOGRAPHIC SYSTEM PRODUCES IMAGES WITH REDUCED SHARPNESS DESPITE CORRECT EXPOSURE PARAMETERS. BASED ON TUBE DESIGN PRINCIPLES, IDENTIFY TWO POSSIBLE TUBE-RELATED CAUSES AND EXPLAIN HOW THEY AFFECT IMAGE QUALITY.

Any questions?

Thank You