CHAPTER 6
THE X-RAY IMAGING SYSTEM

Three Principal Parts of X-ray Imaging System
- X-ray Tube, Operating Console & High Voltage Generator

Radiographic X-ray Tube
- It is attached to an overhead movable crane assembly
- Location: examination room

Fluoroscopic X-ray Tube
- It is located under the examination table

Examination Table
- It must be transparent to x-rays as possible
- Composition: carbon fiber (strong & absorbs little radiation)

Fluoroscopic Table Tilt
- Tilt: 90/30
- 90 degrees to the foot side
- 30 degrees to the head side

High Voltage Generator
- It is housed in an equipment cabinet positioned against a wall
- It is always close to the x-ray tube

OPERATING CONSOLE

Operating Console
- Most familiar to the radiologic technologist
- It is used to control the x-ray tube current & voltage applied to the x-ray tube
- It provides control of line compensation, kVp, mA & exposure time

Radiation Quantity
- The number of x-rays
- The intensity of the x-ray beam
- Units: mR or mR/mAs

Radiation Quality
- The penetrability of the x-ray beam
- It is expressed in kVp or HVL (more precisely)

Line Compensator
- It measures the voltage provided to the x-ray imaging system

AUTOTRANSFORMER

Autotransformer
- It consists of only one winding of wire & one core
- Function: supplies a precise voltage to the filament circuit & high-voltage circuit
- It controls the kVp
- Location: operating console
- Step up voltage approximately twice the input voltage value

Primary Connection
- It conducts the input power to the autotransformer

Autotransformer Law
- It states that the voltage receive & provide by the transformer is directly proportional to the number of turns
- Formula: \( V_s/V_p = N_s/N_p \)

Adjustment of Kilovoltage Peak (kVp)
- Major & minor kVp

kVp
- It determines the quality of the x-ray beam

kVp Meter
- It reads voltage (not kVp)
- Location: output terminals of the autotransformer

Prereading kVp Meter
- It allows the voltage to be monitored before an exposure

X-ray Tube Current
- It is measured in milliamperes (A)
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Filament Temperature
- It determines the number of electrons emitted by the filament

Filament Current
- It controls the filament temperature
- It is measured in amperes (A)
  - Range: 3-6 A

Filament Circuit
- It controls x-ray tube current

Space Charge Effect
- A phenomenon of the space charge that makes it difficult for subsequent electrons to be emitted by the filament because of electrostatic repulsion

Space Charge
- Electron cloud near the filament

Thermionic Emission
- The release of electrons from a heated filament

Precision Resistor
- It is used to reduce the voltage to a value that corresponds to the selected milliamperage

Falling Load Generator
- Design in which exposure factors are adjusted automatically to the highest mA at the shortest exposure time allowed by the high-voltage generator
- Exposure begins at maximum mA & it drops as the anode heats
  - Result: minimum exposure time

mAs
- The product of x-ray tube current (mA) & exposure time (s)
  - A measure of electrostatic charge (C)

mA Meter
- It monitors the x-ray tube current
  - It is connected at the center of the secondary winding of the high-voltage step-up transformer
  - Rationale: ensures electrical safety

Filament Transformer
- Full Name: Filament Heating Isolation Step-down Transformer
- A step down transformer
  - Functions:
    - Received the voltage from the mA selector switch
    - Steps down the voltage to approximately to 12 V
    - Provides the current to heat the filament
  - Primary windings:
    - Thin copper
    - Current: 0.5-1 A
    - Voltage: 150 V
  - Secondary windings:
    - Thick
    - Current: 5-8 A
    - Voltage: 12 V

EXPOSURE TIMERS

Guard Timer
- It terminates an exposure after a prescribed time (6 s)

Timer Circuit
- It consists of an electronic device
  - Make & break the high voltage across the x-ray tube
  - Always done on the primary side
    - Rationale: lower voltage

Four Types of Timing Circuits
- Synchronous Timer, Electronic Timer, mAs Timer & Automatic Exposure Control

Synchronous Timer
- A precision device designed to drive a shaft at precisely 60 revolution per second
- It cannot be used for serial exposures
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Electronic Timer
- Most sophisticated, most complicated & most accurate (as small as 1 ms)
- It allows a wide range of time intervals to be selected
- It is used for rapid serial exposures

High Voltage Transformer
- A step-up transformer
- Secondary Voltage (kVp) > Primary Voltage (V)
- Secondary Current (mA) < Primary Current (A)
- Secondary Windings > Primary Windings
- Voltage Waveform: sinusoidal
- Amplitude: only difference in the primary & secondary waveform

Most exposure timers are electronic & are controlled by a microprocessor!

mAs Timer
- Functions:
  - Monitors the product of mA & exposure time
  - Terminates exposure when desired mAs value is attained
  - Provides the highest safe tube current for the shortest exposure for any mAs selected
- Location: secondary side of the high-voltage transformer
- Applications:
  - Falling-load
  - Capacitor discharge imaging system

Automatic Exposure Control (AEC)
- A device that measure the quantity of radiation that reaches the image receptor
- It automatically terminates the exposure when the image receptor has received the required radiation intensity

Voltage Rectification
- It ensures that electrons flow from cathode to anode only

Rectification
- The process of converting alternating current (AC) to direct current (DC)

Rectifier
- An electronic device that allows current flow in only one direction

Diode
- An electronic device that contains two electrodes

Valve Tube
- A vacuum tube (original rectifier)
- It replaced by solid-state rectifier
  - Composition: silicon

Three Primary Parts
- High Voltage Transformer, Filament Transformer & Rectifiers

Solid-state Detectors
- It is used to check timer accuracy (as short as 1 ms)

HIGH VOLTAGE GENERATOR

High Voltage Generator
- It increases the output voltage from the autotransformer to the kVp necessary for x-ray production

Turns Ratio
- The ratio of the number of secondary windings to the number of primary windings
- Examples: 500:1 & 1000:1
- Directly proportional to the voltage
- Inversely proportional to the current

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Semiconductor
- Lies between insulators & conductors
- 2 Types: p-type & n-type

P-type Semiconductor
- Have loosely bound electrons (free to move)
- Have spaces called holes (no electrons)
Electron flow is used when medical imaging systems are described!

Solid-state p-n Junction
- N-type material placed in contact with p-type crystal
- It conducts electricity in only one direction
- Solid-State Diode: a rectifier

Half-Wave Rectification
- The voltage is not allowed to swing negatively during the negative half of its cycle
  - Diodes: 0, 1 or 2
  - 60 pulses/second
  - Disadvantages:
    - It wastes half the supply of power
    - It requires twice the exposure time

Full-Wave Rectification
- The negative half-cycle corresponding to the inverse voltage is reverse
  - Diodes: 4
  - 120 pulses/second
  - Advantage:
    - Exposure time reduced in half

Single-Phase Power
- It results in a pulsating x-ray beam
  - Disadvantage:
    - X-ray produced has a value near zero

Three-Phase Power
- The voltage impressed across the x-ray tube is nearly constant
  - 6 pulses/1/60 second
  - Advantage:
    - Voltage never drops to zero during exposure
  - Disadvantages:
    - Its size & cost

Extinction Time
- Ending an exposure

High Frequency Generator
- It produces a nearly constant potential voltage waveform
  - Advantages:
    - Much smaller & less costly & more efficient
    - Improves image quality at lower patient radiation dose
  - It uses inverter circuits

Inverter Circuit
- A high-speed switchers or choppers that convert DC into a series of square pulses

Capacitor Discharge Generator
- Tube voltage falls during exposure
- Approximately 1 kV/mAs

Grid-Controlled X-ray Tube
- An automatic lead beam stopper
- It stops continues x-ray emission of capacitor bank
- It is designed to be turned on & off very rapidly
  - Applications:
    - Portable capacitor discharge imaging systems
    - Digital subtraction angiography
    - Digital radiography
    - Cineradiography
  - Grid: it refers to an element in the tube that acts as a switch

Less Voltage Ripple
- Greater radiation quantity
  - Higher efficiency of x-ray production
• Greater radiation quality
  o Fewer low-energy projectile electrons pass from cathode to anode

### CHARACTERISTICS OF HIGH FREQUENCY X-RAY GENERATORS

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Inverter Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 kHz</td>
<td>Thyristors</td>
</tr>
<tr>
<td>1-10 kHz</td>
<td>Large silicon-controlled rectifier</td>
</tr>
<tr>
<td>10-100 kHz</td>
<td>Power field effect transistors</td>
</tr>
</tbody>
</table>

**Voltage Ripple**

• Means of characterizing voltage waveforms

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Ripple</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Phase:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half-wave</td>
<td>100%</td>
<td>Varies from zero to maximum</td>
</tr>
<tr>
<td>Full-wave</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Three-Phase:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-pulse</td>
<td>14%</td>
<td>Never falls below 86% of maximum value</td>
</tr>
<tr>
<td>12-pulse</td>
<td>4%</td>
<td>Never falls below 96% of maximum value</td>
</tr>
<tr>
<td>High Frequency</td>
<td>&lt; 1%</td>
<td>Never falls below 99% of maximum value</td>
</tr>
</tbody>
</table>

**Power Rating (kW)**

• *Formula* for three-phase & high frequency
  o \((\text{mA} \times \text{kVp})/1000\)

• *Formula* for single-phase
  o \((0.7)(\text{mA} \times \text{kVp})/1000\)

**Three Main Section of X-ray Imaging System**

• X-ray tube, Operating Console & High-Voltage