Chapter 5

X-RAY EQUIPMENT (CIRCUITS AND IMAGING SYSTEMS)
Topics

- X-ray Systems
- Power: Single-Phase vs. Three-Phase
- Circuit
  - Main X-ray Circuit
  - Filament Circuit
- Generators: Single-Phase, Three-Phase (6 and 12 pulse), High Frequency, Capacitor Discharge, Battery, Falling Load
There are two major classifications of medical equipment, and x-ray equipment fits this system:

- **Diagnostic**: detects problems
  - Ex.: regular ol’ x-ray machine, panorex, CT scanner
- **Therapeutic**: fixes problems
  - Ex.: linear accelerators (cancer therapy), gamma knife
What makes a good x-ray table?

1. It needs to hurt the patient. (Just kidding... we don’t want it to hurt the patient, we just don’t care if it hurts [also just kidding... we do care, it’s just other things are more important]).

    Actually, we just need strong material with a uniform surface (like Bakelite or carbon graphite fiber) that won’t make artifacts.

    But now we have radiolucent pads that make it (slightly) more comfortable without producing an artifact.
What makes a good x-ray table?

- Most tables are flat (so they can float), but specials will usually use a curved table (because the tube moves around them) which allows a smaller OID.

- Curved tables are terrible for regular x-rays because it makes it hard to position obliques and you can’t really put a flat IR on/under it.
X-ray Systems - Tables

2. We need it to be easy to clean and difficult to damage.
   - Damage creates artifacts and crevices where spilled contrast can go, which makes more artifacts.

3. We need space for an image receptor, like a bucky.
   - The bucky was named after Dr. Gustav Bucky, which is the most scientisty scientist name that has ever scienced in the history of science.
X-ray Systems - Tube Supports

- **Overhead Suspension System:**
  - Most common: just like in all three of our practice rooms.
  - One of the more versatile systems: allows you to adjust longitudinally, transversely, and vertically.
X-ray Systems - Tube Supports

- **Overhead Suspension System**
  - The locking mechanism holds the tube in place when it is not necessary to move it. This can work multiple ways (you do not need to know these individually, I just thought you might find it interesting):
    - An electromagnet which activates to hold the tube in place (the downside is that it needs power constantly, which is dangerous).
    - An electromagnet whose core is made of a permanent magnet, rather than a piece of iron. The magnet is positioned so that its magnetic field is negated when the electromagnet is activated.
    - A solenoid attached to a spring-loaded brake pad. Activation of the solenoid pulls the brake pad away (the book only mentions this one in passing).
    - A rotary “tooth” lock, which uses two plates with fine teeth instead of a brake pad, one of which is spring loaded and controlled with an electromagnet.
**Overhead Suspension System**

Detents can be established in the following ways:

- A **spring-loaded ball** which fits into a slot along the track.
- A **cam operated micro-switch**.
- An **optical sensor**. All of these activate the locking mechanism at specific locations.

Hopefully, you can see how intricate these locking mechanisms are, and why it’s important not to just whip the tube around.
X-ray Systems - Tube Supports

- **Floor Suspension System:**
  - This system utilizes a support column mounted to the floor.
  - Manufactures have to be careful to balance it.
X-ray Systems - Tube Supports

- **Floor-to-Ceiling Suspension System**
  - This system uses a pair of rails, one on the floor and one on the ceiling, to move the tube.
  - This helps deal with the balancing issue. This system might also be useful with high ceilings.
X-ray Systems – Other Specialized Diagnostic Equipment

- Stuff you might not have seen yet:
  - Panoramic Dental/Facial Unit
  - Tomogram
  - Kidney Tomogram
Standard incoming line voltage in the US is 60 Hz, 240V.

That doesn’t mean, however, that you’re getting all 240 of those volts.

The actual voltage range (the nominal root mean square, or rms, voltage) is somewhere between 200 and 240V.

There are two “hot” wires and a neutral ground wire.

Each of the hot wires has a voltage of 120V (120 + 120 = 240).

They are also out of phase with each other (when one wire is in the positive portion of the wave, the other is in the negative, and vice versa).

Because the two wires are out of phase, the average voltage typically ends up around 210 to 220 volts.
When an x-ray tube is supplied power by a single-phase (1φ) generator, the voltage returns to zero every half cycle (Voltage ripple = 100%):

- The voltage is directed in the positive direction, then in the negative direction (reversing the direction of the current), making a full cycle.

The problem with single phase power is that, even when rectified, useful x-rays are only produced when the induced voltage is near one of the peaks of the waveform.

- The rest of the time, either no photons are produced, or they are of such low energy that they cannot exit the tube.
Power - Single Phase

- Because the voltage ripple is 100%, the mathematical average of the voltage is zero (0); this is not, however, an accurate reflection of the energy being used by the system.

- To more accurately reflect the energies, we use a concept called the Root Mean Square (RMS). The RMS is a way of finding something like an “average” value for a constantly changing dynamic system.

- In single-phase systems, the RMS voltage is calculated as 70.7% \( \left( \frac{1}{\sqrt{2}} \right) \) of the peak voltage.

- The value would be higher for 3-phase systems, because the average energy is higher.
What is the approximate RMS voltage of a single-phase sine wave with a peak of 120 kVp?

\[
\text{rms voltage} = 70.7\% \text{ of peak kVp} = \frac{70.7}{100} \times 120 \text{ kVp}
\]

\[
\text{rms voltage} = 84.84 \text{ kV}
\]

This means that a single phase system, producing an x-ray at 120 kVp, uses the same amount of energy as a constant potential (direct current) system producing an x-ray at 84.84 kV.
Involves 3 sine waves running from the generator simultaneously, out of phase with each other by 120°.

This substantially reduces the voltage ripple (demonstrated in red) from the 100% in single phase systems.
X-ray Circuit

Click on any component for more information:
1. Main Breaker:

- A main circuit breaker is a switch that is used to isolate the line current/voltage from the x-ray machine. Breaking the circuit allows maintenance to be performed on the equipment in a de-energized state.

- A circuit breaker also prevents fire.
  - The line voltage fluctuates as it comes to the machine; if it were to get too high, it could cause arcing. The circuit breaker prevents this.
  - The line current can also fluctuate; if it were to get too high, the x-ray machine would get hot, which can cause a fire.
2. Exposure Switch:

- The exposure switch is a dead-man switch; it completes the circuit, allowing current to flow.
  - Releasing the switch breaks the circuit, stopping current flow.
- Most exposure switches now are two stage:
  1. Holding the exposure switch halfway down brings the rotor up to speed.
  2. Pressing it down the whole way completes the circuit.
- It is recommended that both stages be pressed together in one motion.

On portable machines, the cord must be a minimum length of 6 feet, to allow the radiographer to move as far as possible from the x-ray tube during exposure.
3. **kVp Selector:**

- The kVp selector is an autotransformer.
  - It works on the principle of self-induction, so the primary and secondary coils are on the same coil.
  - The number of turns on the primary side is determined by the length of the coil.
  - The number of turns on the secondary side is selected on the control panel.
- The kVp selector has to be placed on the low-voltage side of the x-ray circuit because it does not function well in high voltage settings.
4. Timer Circuit:

- A timer circuit allows the x-ray machine to shut itself off after a very precise length of time. This allows for more accurate exposure times.
  - Earlier units utilized a thyristor as a timing device; newer units utilize a silicon-controlled rectifier (SCR).
  - Modern timers are capable of accurate exposures as short as 0.001 seconds, with a 1 msec delay.

- Milliampere-second timers are used in falling load generators and some capacitor discharge units.
5. Step-Up Transformer:

- Has fewer windings on the primary side than on the secondary side, usually by a factor of ~850-1000 V.
- This allows the x-ray machine to increase the voltage from line voltage (~210-220 V) to the kilovolt range.
- This also results in a substantially reduced current, going from amps to milliamps.
6. Four-Diode Rectifier Array:

- The rectifier array converts AC current, coming from the line voltage, to DC current, going through the x-ray tube.
- The array consists of 4 solid-state semiconductor diodes arranged in a diamond configuration:
  - This allows for full-wave rectification.
7. mA Selector:

- The mA selector adjusts the amount of electricity flowing through the x-ray tube.
  - This was formerly a rheostat; more contemporary units utilize variable resistors.

- Variable resistors work through Ohm’s law:
  - By increasing the resistance, they decrease the amount of current allowed to flow, and vice versa.
8. Step-Down Transformer:

- Has fewer windings on the secondary side than on the primary side.
  - This lowers the voltage in the filament circuit to 6-12 Volts.
  - The step-down transformer will also increase the current in the filament circuit to 5-7 amps.
- The turns ratio is smaller in magnitude than the high-voltage step-up transformer.
9. X-ray Tube:

- Produces X-ray photons
- Discussed in detail in Chapter 6

Return to X-ray Circuit Diagram
10. Stator Electromagnets:

- The stator electromagnets are located outside the glass envelope of the x-ray tube, but within the lead housing.
- When a current flows through the windings, they create a magnetic field that causes the rotor, which is attached to the anode, to spin.
mA Meter (Main X-ray Circuit):

- The mA meter is located on the secondary side of the step-up transformer.
- That’s because this is where the conversion from amps to milliamps occurs in the main x-ray circuit.
- This meter therefore shows tube current.
Ammeter (Filament Circuit)

- This is located on the secondary side of the step-down transformer.
- It measures the current flowing through the filament circuit, not the tube current.
Generators – Single Phase

- Single phase generators allow the waveform to return to zero twice every cycle (i.e., it has 100% voltage ripple), which means they’re kinda garbage, as far as quality equipment goes.

- To calculate the power produced by these units, you have to remember that the RMS value of the waveform is 70.7% of the peak kVp.

- This means that the power produced is roughly 70% of the peak power.

- So when calculating the power (P=IV) with a single phase generator, you have to use a constant (0.7) that represents this reduction in power from using garbage quality equipment.

- Which just means that Power (for a single phase unit) = 0.7 x (mA) x (kVp)
Generators - Three Phase

- When using a three phase unit, the reduction in the voltage ripple means that the wave form spends more time closer to the peak voltage.
  - This means you don’t have to use a constant to account for the power loss any more, because the equipment doesn’t suck as much.
- Three phase generators come in two varieties:
  - Three phase, six pulse (3φ, 6P) has about a 13-25% voltage ripple. This already gives it about 35% higher energy than a 1φ.
  - Three phase, twelve pulse (3φ, 12P) is a little better, at 4-10% voltage ripple.
High Frequency generators use inverters to smash a whole bunch of squished up waves into a short amount of time.

Inverters are devices that transform DC power into AC power. When you use them in high frequency generators, they produce an extremely small voltage ripple (<1%). So they’re like, real good.
Capacitor Discharge Units

- This kind of equipment would typically be used in mobile equipment.
- It works as a chargeable capacitor (stores charge), but once you hit the exposure switch, it immediately starts losing power.
  - The initial drop in power is pretty significant, especially initially after exposure. This has a big effect on the rms voltage.
  - Also, the exposure can keep going after the exposure is supposed to be completed.
Battery Operated Mobile Units

- This is a better technology for mobile radiography.
  - The batteries are charged using AC power.
  - They discharge, however, with DC power similar to 3φ, 12P units (or better).
  - They do a better job of shutting off at the right time, delivering a higher rms voltage, and providing a more consistent exposure.
Falling Load Generators

This section is always confusing, and the book doesn’t help.

Falling load generators were made because a good, constant potential generator is expensive. So companies were buying cheaper generators, but these generators didn’t have the ability to achieve very high mAs or kVp.

So if you had a larger patient, you’d have to set a really high exposure time in order to get a good picture.

So rather than fork out the cash for a better generator, they invented falling load generators. This is a more cost-affordable option that reduces exposure time.
Falling Load Generators

- Falling load generators “take advantage of the tube’s loading capacity”.
  - This means that the tube is capable of handling higher mAs than the generators.
  - So the falling load generator starts out at a higher mA for a little while, then drops down to a lower mA, then again.
  - This allows the machine to terminate the exposure earlier than would be necessary if a lower-quality constant potential generator were used.
- So falling load generators are useful for a very specific kind of situation: minimizing exposure time in heavy-load situations (e.g., large patients)
Falling Load Generator

- Disadvantages:
  - They cause extra wear on the x-ray tube, especially the filament.
  - The tech can’t control the mA, which further means that the tech also can’t set the time (bad for breathing techniques).
Automatic Exposure Controls - Phototimers

- So automatic exposure controls (AEC) terminate the exposure at a specific time, so that you don’t have to set a mAs for yourself (please try not to become overly reliant on these though).

- Everybody calls these devices “phototimers,” although phototimers were a very specific kind of AEC.
  
  - Most AEC are ionization chambers now.
Automatic Exposure Controls - Ionization Chambers

- Ionization chambers are basically little chambers of air. As the radiation passes through the air, it ionizes it (splits the molecules into positively and negatively charged species).
- Also in the chamber are two oppositely charged plates.
  - Once the air ionizations are produced, they migrate to the plate with the opposite charge, producing a fluctuation in the charge.
  - Once the charge fluctuates to a preset amount, the machine shuts off the exposure.
Automatic Exposure Controls - Minimum Reaction Time

- Part of the trick of making a good AEC is getting it to shut off quickly.
  - Back in the day, they used a device called a thyristor, but it had garbage reaction times (0.05 seconds).
  - Now, we use silicon-controlled rectifiers (SCRs), which have a reaction time of <0.001 seconds.
- You definitely don’t want to use AEC for something really thin, like a distal extremity. The machine may not be able to stop quickly enough.
Automatic Exposure Controls - Backup Time

- So you have to set a backup time to make sure that if the AEC malfunctions, the exposure won’t just keep going forever.

- The rule is that backup time shouldn’t exceed the tube limit and should be set at 150% of what you think the mAs ought to be.

- So just because you’re using AEC, that doesn’t mean you can turn your brain off regarding technique.
That’s all I have.

- I wish you all the best.

- Ian