APPH 226: Generators and the X-Ray Circuit

Objectives: 1.2, 1.3, 1.5, 2.1

MRT Program

Electrodynamics Terminology

- Electrodynamics
  - Study of electric charges in motion
- Electricity
  - When an electric potential is applied to a wire, allowing the flow of electrons
- Electric Circuit
  - Path of electron flow from a source, through various components and back to the source

- Flow of electrical current is in the opposite direction of the flow of electrons

Electrodynamics

- Two types of Electric Current
  - Alternating Current (AC)- changes direction in cycles as the electric potential changes (negative and positive)
  - Direct Current (DC) – flows only in one direction (from positive to negative, opposite the direction of electron flow)

General X-Ray Circuit

- Basic X-ray Circuit can be divided into:
  - Main X-Ray Circuit
    - Purpose: to produce x-rays
    - Supplies x-ray tube with properly modified power so that it can produce x-rays
  - Filament Circuit
    - Purpose: to produce appropriate electron cloud
    - Supplies filament of x-ray tube with properly modified power to produce appropriate thermionic cloud

Components of General X-ray Circuit

- Main X-Ray Circuit
  - Primary Side/Circuit
    - Main power switch, circuit breakers, autotransformer, timer circuit and primary side of the step up transformer
  - Secondary Side/Circuit
    - Secondary side of step up transformer, mA meter, rectifier bank, x-ray tube (except filaments)
- Filament Circuit
  - Rheostat, step down transformer, filaments

Main X-Ray Circuit

- Modifies the incoming line power to produce x-rays
- Achieves this with a sequence of devices
- Circuit needs to boost the voltage up to the range required to produce x-rays
- Must permit the technologist to adjust the amperage, voltage and length of exposure

Primary Circuit

- Main power switch:
  - An on-off switch for the unit that is connected to the power supply of the facility
- Line compensator
  - Used because the incoming power isn't a consistent 220 volts
  - Usually wired to the autotransformer
  - Automatically adjusts the power supply to precisely 220 volts – must stay constant
- Circuit breakers
  - Protect against short circuits and electric shock

Primary Circuit

- Autotransformer
  - Operates on the principle of self induction
  - Only has one coil of wire around a central magnetic coil
  - This coil is used as the primary and secondary coil
  - Outside wires are attached at different points along the coil, and the induced voltage is adjustable depending on where the connections are made.

Autotransformer

- Only one core
- Power brought in on one side -“primary connections”
- Depending on the kVp set, different combinations of the secondary connections can increase or decrease the voltage

Autotransformer

- Adjustable transformer controlled by kVp selector on control panel
- When a tech selects the kVp setting, they are controlling this transformer
  - Determines # of turns on the secondary side to be included – which controls the output voltage
- Sometimes called kVp selector
- Primary purpose is to provide a voltage that will be increased by the step up transformer to produce the kilovoltage selected at the operating console

Primary Circuit

- Step up Transformer
  - Dividing line between primary and secondary circuits
  - Increases voltage from the autotransformer to the kV required for x-ray production
    - Not adjustable , increases kV by a fixed amount
  - Primary coil is in primary circuit, secondary coil in secondary circuit

Primary Circuit

- Timer circuit (exposure timer)
  - Located in the primary circuit because it's easier to control a low voltage vs a very high one (secondary circuit)
  - Purpose of the device is to 'make or break' the voltage across the tube
  - Four types:
    - Synchronous timer
    - Electronic timers
    - mAs timers
    - AEC

Secondary Circuit

- Begins with other side of step up transformer
- An mA meter is there to monitor x-ray tube current
- AC is required for the transformers to work properly, but the x-ray tube requires DC
  - In the tube, electrons must always flow cathode to anode

Rectifiers

- Purpose: to convert AC (alternating current) to DC (direct current)
- Solid state rectifier commonly used
- Consists of two semiconducting crystals joined together to form a solid state diode
  - P-type crystal
    - 'electron traps/holes'
    - Traps are mobile
  - N-type crystal
    - Abundance of freely moving electrons

Rectifiers

- When a positive charge is placed on the p-type crystal, and negative charge on the n-type crystal, the diode will conduct electricity
- Both the traps and the electrons will move across the PN junction allowing current to flow

Rectifiers

- When AC cycle reverses, the diode will not conduct
- The traps and electrons do not move to the junction and no current is conducted

Rectifiers

- Solid state p-n junction conducts electricity in only one direction
  - Junction is called diode
- Solid state diodes are rectifiers because they conduct electric current in one direction
  - One way valve
  - Necessary to route the electricity through the x-ray tube correctly
- Arrowhead in the diode symbol indicates direction of conventional electric current, which is opposite to the flow of electrons

Why do we need rectifiers?

- When the cathode is negative and the anode is positive
  - Electrons will move across and x-rays will be produced
- If the anode of the x-ray tube is negative and the cathode positive
  - X-rays will not be produced
  - Anode is not constructed to emit electrons, so there will be no electrons moving to the cathode

Unrectified Voltage

- Current that passes through the x-ray tube exists only during the positive half of the cycle, when the cathode is negative and anode is positive
- During the negative half of the cycle, current flows from anode to cathode, but this is not possible as the anode cannot emit electrons

Half Wave Rectification

- Inverse voltage is removed from the supply to the x-ray tube by rectification
- Done through the arrangement of rectifiers to convert AC to DC
  - Need DC for x-ray tube to operate
- During positive portion of AC waveform, the rectifier allows electric current to pass through tube
- During negative portion of AC waveform, the rectifier does not conduct, no electric current is allowed

Half Wave Rectification

- Result is positive pulses with gaps when current is not being conducted
- Resultant electric current is rectified because the electrons flow in only one direction
- Called half wave rectification because only one half of the AC waveform appears in the output

Full Wave Rectification

- Major shortcoming of half wave rectification is that it wastes half of the power supply, and thus requires double the exposure time
- When 4 rectifiers are used, able to utilize the negative half cycle
- Inverts the negative half so that the anode is always positive

Full Wave Rectification

- Energy fluctuates from maximum voltage to zero – 100% ripple
- This is a problem for x-ray production
- X-rays produced will vary from zero to kVp selected on console

Rectification

- Not very effective when the energy level drops to zero
- One solution is to use 3 AC waveforms at the same time, but slightly out of phase or synchronized
- Each is generated independently and then phased so they are 120 degrees out of step with the next (out of step by 1/3)

Three phase power

- After rectifying, called three phase power
- Depending on the number of rectifiers and engineering, can have ripple anywhere from 4-14%

Three Phase Power

- Major improvement over the single phase generator where 100% ripple meant voltage supply to the tube would produce x-rays between 0-100% of the kVp set
- 3 phase 6 pulse
  - 14% ripple
  - Voltage supply to x-ray tube never falls below 86%
- 3 phase 12 pulse
  - 4% ripple
  - Voltage supply to x-ray tube never falls below 96%

High Frequency Generators

- The next step in improving the waveform is the use of HF generators
- Takes the regular 60 Hz and converts it to higher frequency and transfers it to high voltage
  - Using capacitors, rectifiers, transformers
- Major advantages:
  - Smaller size
  - Less costly to produce
  - Produces a nearly constant voltage
    - Minimal ripple – less than 1%

Efficiency

- Advantages of having less ripple are:
  - Greater radiation quantity and quality produced from the more constant voltage supplied to the tube
  - Quantity of photons is higher because the efficiency of x-ray production is higher when the tube voltage is high
    - Reproducibility of exposure
  - Fewer low energy photons

In the secondary circuit

- When the exposure switch is pressed, let's summarize what happens in the primary circuit:
  - Voltage goes through step up transformer, to increase to the kilovoltage selected on control panel
  - kV goes through rectifiers so that it travels through the tube correctly to produce x-rays
    - Large positive charge on anode
    - Large negative charge on cathode
- To create x-rays, need one more thing:

  electrons

Filament Circuit

- Goal: to boil electrons out of the filament wire
- The filament is a very small wire
  - Must control the current that goes through it or else it could be damaged or destroyed
  - Filament temperature is controlled by the filament current – measured in amperes
  - A step-down transformer is used to reduce the voltage applied to the filament
- mA parameter is called tube current because it reflects the rate of flow of electrons through the tube during an exposure

Filament Circuit - Rheostat

- This circuit begins with the rheostat
  - Controlled by the mA selector on the console
  - As adjustments are made to the mA on the console, the tech is actually making adjusts to the rheostat which adjusts the amount of resistance in the filament circuit, and ultimately the amount of current applied to the filament.
  - Rheostat – variable resistor
    - Controls filament temperature and the rate at which electrons are boiled off the filament
  - Adjustments in mA = adjusting the resistance of the current in the filament circuit
    - The higher the mA, the lower the resistance

Filament Circuit

- To provide voltage for the filament circuit, there are connections on the autotransformer
  - From the autotransformer, the voltage goes to the rheostat, and then a step down transformer
- Resistors are used to reduce the voltage to correspond with the selected mA
  - Resistors are in fixed stations to provide specific mA 'stations' – example…100, 200, 300 mA etc…

Filament Circuit

- Rheostat works together with the exposure timer
- Rheostat controls filament temperature and the electrons being emitted, and the timer determines the duration of this process
- Together they determine the quantity of electrons boiled off and available to produce x-rays
- Step down transformer is used to reduce the voltage applied to the filament

Filament Circuit Summary

- When exposure button is pressed, voltage and current is sent through the filament circuit
- Quantity is controlled by rheostat to reflect the mA selected
- Step down transformer is used to reduce the voltage and increase current (inverse relationship)
- Current heats the selected filament and begins boiling off electrons
- Time selected controls how long the voltage and current is applied to the tube

Summary of Circuit Operation

- On the console, select the kVp, mA, exposure time and focal spot size
- Follow voltage through the primary and secondary circuit
- Follow current through the filament circuit

Path of Circuit

- 1. kVp selected adjusts the autotransformer
  - Determines the number of turns on the secondary side necessary to produce a voltage to send to the step up transformer
  - Step up transformer increase this voltage by a fixed amount and produces the kV selected on the console
  - This transformer represents the transition from the primary (low voltage) to the secondary (high voltage) circuit

Path of Circuit

- 2. kV is created, now it must be rectified for the x-ray tube
  - Electrons must flow from cathode to anode
  - Rectifiers (one way valves) will route the electricity through the tube correctly
  - After passing through the rectifiers, the electricity will create a large positive charge on the anode, and a large negative charge on the cathode (focusing cup)

Path of Circuit (Filament)

- Filament circuit draws electricity from the autotransformer to the rheostat
- Rheostat is controlled by mA selector on the console and is connected to the focal spots
- Focal spot selector represents the filaments in the tube
- mA station selection will also determine which filament is selected

Path of Circuit (Filament)

- Selected mA sets the resistance in the filament circuit
- From the rheostat, electricity travels to the step down transformer
- Adjusted current travels to the filament
- Filament is heated up and thermionic emission occurs

Path of Circuit

- Now the paths join
- Electron cloud created by the filament is ready and waiting
- kV applied to the x-ray tube creates a large positive charge on the anode and a large negative charge on the cathode (focusing cup)
- Positive charge on anode draws the electrons over, giving them tremendous kinetic energy in the process

Path of Circuit

- Opposites attract and in the short 1-3 cm gap between cathode and anode the electrons reach speeds of up to ½ the speed of light
- Negative charge on cathode serves to keep electrons crowded together
- Electrons travel to the anode and interact there to produce x-rays until the timer circuit terminates the process

Falling Load Generator

- Uses the shortest exposure time possible
- Method: initial tube loading is higher, and drops during exposure
- Results in achieving the set mAs, in a shorter exposure time
- Principal use in areas where the shorter the exposure time, the better
  - Interventional radiology

Emission Spectrum and Generator

- X-ray production varies at different part of the voltage cycle
- Quantity of x-rays is greater at peak voltages than at lower voltages
- Results in considerably higher x-ray emission for 3 phase or HF waveforms

Emission Spectrum and Generators

- As the efficiency of the voltage wave form increases, the efficiency of x-ray production increases also
- High frequency generators have the lowest ripple, so they will be at peak voltage for most of the duration of the exposure
  - Meaning more efficient production of x-rays (quantity) and higher energy x-rays produced (higher average)
- Single phase generators have the most ripple
  - Less efficient production of x-rays, lower average energy

Readings

- Bushong: Radiologic Science for Technologists 11th Edition
  - Pg 86-102
  - If you would like to review Electricity, Magnetism and Electromagnetism : Read over Chapter 4 pg 61-81