GENERATING THE TUBE VOLTAGE

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Fundamental of Radio Physics

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Outline

- Generating the Tube Voltage
  - Exposure timing
  - Falling load
  - Filament voltage

Objectives

The student should be able to do the followings;

- Describe how to generate the x-ray tube voltage
- Explain the importance of the tube voltage on exposure time
- Analyze the effect of falling load
- Explain the Filament voltage

Generating the Tube Voltage

The intensity and energy distribution of x rays emerging from an x-ray tube are influenced by the potential difference (voltage) between the filament and target of the tube. The source of electrical power for radiographic equipment is usually alternating current (ac). This type of electricity is by far the most common form available for general use, because it can be transmitted with little energy loss through power lines that span large distances. Figure 5-2 shows a graph of voltage and current in an ac power line. X-ray tubes are designed to operate at a single polarity, with a positive target (anode) and a negative filament (cathode). X-ray production is most efficient (more x rays are produced per unit time) if the potential of the target is always positive and if the voltage between the filament and target is kept at its maximum value. In most x-ray equipment, ac is converted to direct current (dc), and the voltage between filament and target is kept at or near its maximum value (Figure 5-3). The conversion of ac to dc is called rectification.

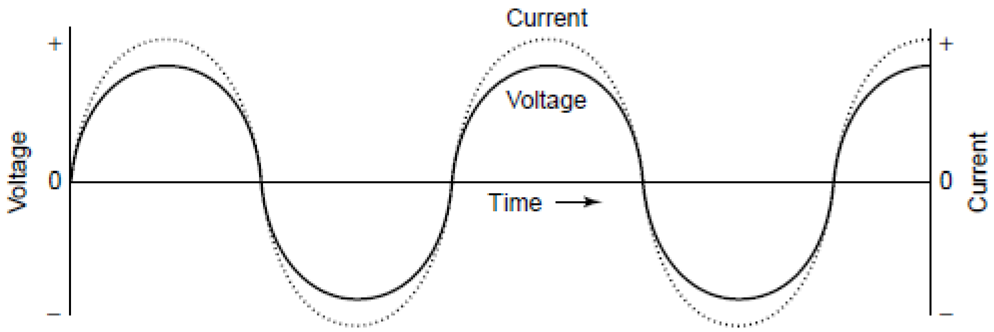


FIGURE 5-2

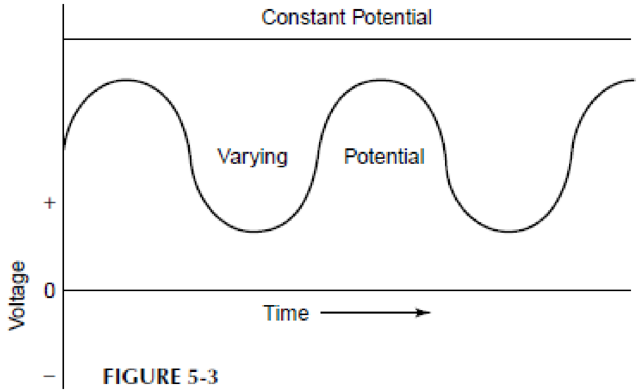


FIGURE 5-3

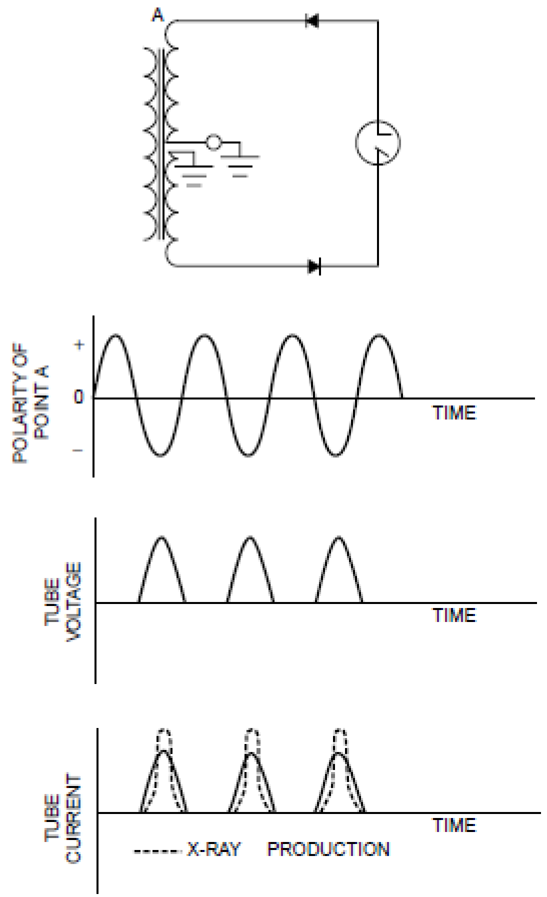
Generating the Tube Voltage

One of the simplest ways to operate an x-ray tube is to use ac power and rely upon the x-ray tube to permit electrons to flow only from the cathode to the anode. The configuration of the filament (a thin wire) is ideal for producing the heat necessary to release electrons when current flows through it. Under normal circumstances the target (a flat disk) is not an efficient source of electrons. When the polarity is reversed (i.e., the filament is positive and the target is negative), current cannot flow in the x-ray tube, because there is no source of electrons. In this condition, the x-ray tube "self-rectifies" the ac power, and the process is referred to as self-rectification. At high tube currents, however, the heat generated in the target can be great enough to release electrons from the target surface. In this case, electrons flow across the x-ray tube when the target is negative and the filament is positive. This reverse flow of electrons can destroy the x-ray tube.

A rectified voltage waveform can also be attained by use of circuit components called diodes. Diodes are devices that, like x-ray tubes, allow current to flow in only one direction. Rectification in which polarity reversal across the x-ray tube is eliminated is called half-wave rectification.

Generating the Tube Voltage

A half-wave rectifier converts ac to a dc waveform with 1 pulse per cycle. X-ray production could be made more efficient if the negative half-cycle of the voltage waveform could be used. A more complex circuit called a full-wave rectifier utilizes both half-cycles. In both the positive and negative phases of the voltage waveform, the voltage is impressed across the x-ray tube with the filament (or cathode) at a negative potential and the target (or anode) at a positive potential. This method of rectifying the ac waveform is referred to as *full-wave rectification*. In fullwave rectification the negative pulses in the voltage waveform are in effect "flipped over" so that they can be used by the x-ray tube to produce x rays. Thus a fullwave rectifier converts an ac waveform into a dc waveform having 2 pulses per cycle.



MARGIN FIGURE 5-5
A circuit for half-wave rectification (**top**), with resulting tube voltage, tube current, and efficiency for production of x rays. Rectifiers indicate the direction of conventional current flow, which is opposite to the actual flow of electrons.

Exposure timing

For any given radiographic examination, the number of x-rays that reach the image receptor is directly related to both the x-ray tube current and the time that the x-ray tube is energized. X-ray operating consoles provide a wide selection of x-ray beam-on times and, when used in conjunction with the appropriate mA station, provide an even wider selection of values for mAs.

Question: A KUB examination (radiography of the kidneys, ureters, and bladder) calls for 70 kVp, 40 mAs. If the radiologic technologist selects the 200 mA station, what exposure time should be used?

$$exposure\ time = \frac{40\ mAs}{200\ mA} = 0.2\ s = 200\ ms$$

Question: A lateral cerebral angiogram calls for 74 kVp, 20 mAs. If the generator has a 1000 mA capacity, what is the shortest exposure time possible?

$$exposure\ time = \frac{20\ mAs}{1000\ mA} = 0.02\ s = 20\ ms$$

Falling load

Many x-ray imaging systems today engage a falling load technique to ensure the shortest possible exposure time. The x-ray tube anode can accommodate only a limited heat level.
Supposing the limit on exposure time, and therefore x-ray intensity, for an interventional radiology imaging system at the 1000 mA station is 500 ms and therefore 500 mAs as shown in Figure 5-27. At the selected kVp and 1000 mA, the shortest exposure time allowed is 500 ms because of the thermal capacity of the x-ray tube anode.

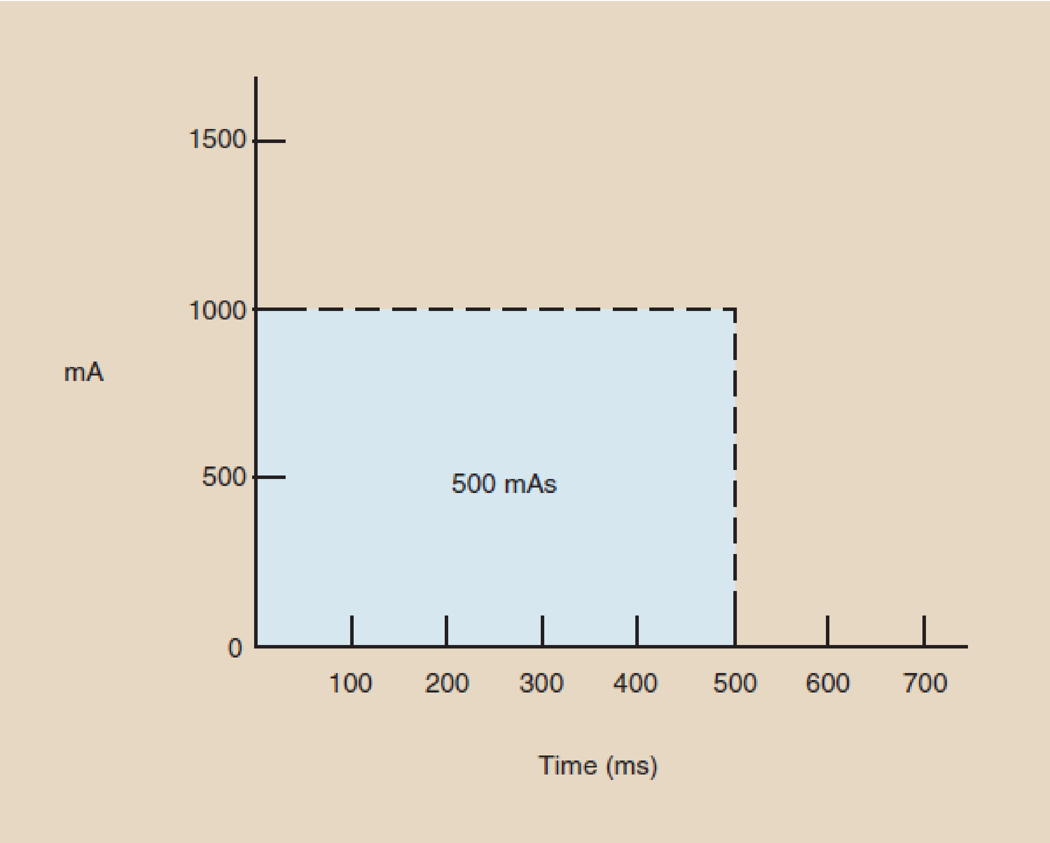


FIGURE 5-27 A fixed radiographic technique of 1000 mA, 500 ms results in 500 mAs, the area of the box.

Falling load

When an x-ray tube anode is heated, it immediately begins to cool. The approach of falling load voltage generation is that the initial tube loading is higher and drops during exposure as shown in Figure 5-28. The rate of drop follows the cooling characteristics of the x-ray tube anode. The result is the same 500 mAs at shorter exposure time, 300 ms in this example. Falling load voltage generation finds principal use in high-capacity x-ray imaging systems such as interventional radiology in which the shorter the exposure time the better.

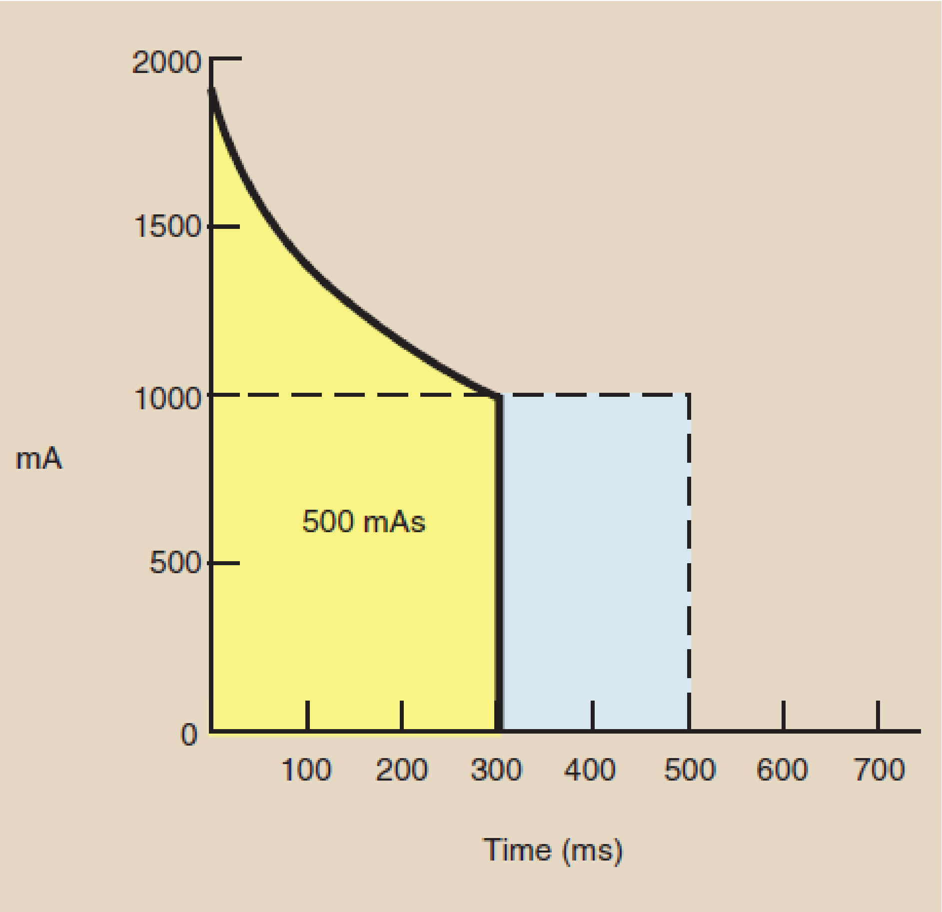


FIGURE 5-28 Application of falling load to achieve 500 mAs results in a much shorter exposure time, 300 ms.

Filament voltage

The maximum voltage to be applied between filament and target is specified for every x-ray tube. This “voltage rating” depends on the characteristics of the applied voltage (e.g., single phase, three phase, or constant potential) and on the properties of the x-ray tube (e.g., distance between filament and target, shape of the cathode assembly and target, and shape of the glass envelope). Occasional transient surges in voltage may be tolerated by an x-ray tube, provided that they exceed the voltage rating by no more than a few percent.

Limits are placed on the current and voltage delivered to coarse and fine filaments of an x-ray tube. The current rating for the filament is significantly lower for continuous compared with pulsed operation of the x-ray tube, because the temperature of the filament rises steadily as current flows through it.

Filament voltage

Maximum Energy: Maximum-energy ratings are provided for the target, anode, and housing of an x-ray tube. These ratings are expressed in heat units, where for single-phase electrical power.

$$Number\ of\ heat\ units\ (HU) = (Tube\ voltage)(Tube\ current)(Time)$$
$$= (kVp)(\text{mA})(\text{sec})$$

If the tube voltage and current are constant, then 1 HU=1J of energy. For three-phase power, the number of heat units is computed as

$$Number\ of\ heat\ units\ (HU) = (Tube\ voltage)(Tube\ current)(Time)(1.35)$$
$$= (kVp)(mA)\ (\text{sec})\ (1.35)$$

For x-ray tubes supplied with single-phase (1ϕ), full-wave rectified voltage, the peak current through the x-ray tube is about 1.4 times the average current. The average current nearly equals the peak current in x-ray generators supplied with three-phase (3ϕ) voltage. For this reason, the number of heat units for an exposure from a 3ϕ generator is computed with the factor 1.35 in above Eq.

References

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