Some things to consider when selecting an x-ray tube

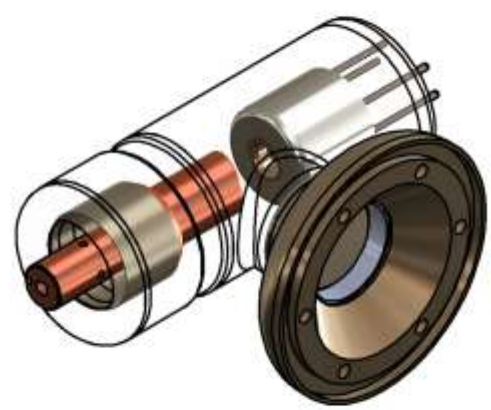
There are many considerations that go into the selection of an x-ray tube. In this document I will provide the reader with many of the considerations I have found helpful in my more than thirty-six years designing x-ray tubes, x-ray tube assemblies and high voltage power supplies.

Power Supply
There are many different topologies employed for high voltage power supplies, used to drive an x-ray tube. Those topologies will be discussed in another document. The subject I am trying to drive home here is the consideration of bi-polar vs single ended power supplies.

Bi-polar supplies are typically employed when the tube is designed to operate at kVs in excess of 75 kV. There is a good reason for this…space considerations. Prior to the tube being in the same housing as the high voltage power supply, the tube housing used Federal High Voltage Wells and high voltage cables to deliver the high voltage from the power supply to the tube head. The Federal High Voltage Wells were rated at a maximum of 75 kV. New HV well designs have changed this over the past several years.

Side ported tubes typically use a bi-polar power supply. The bi-polar supply delivers both a negative and positive potential equal in amplitude. Side ported tubes can be all glass or incorporate a metal flange. The flange typically incorporates a low z window material like beryllium.

Side ported



Side ported with Flange

Single ended supplies are generally used when the tube will be used at low voltage (50 kV or less). Higher voltages require larger standoff distances leading to a physically larger power supply. Additionally, the high voltage wells and the high voltage cables also get larger.

There are other considerations to be studied when selecting a single ended power supply. Here are two examples. If the technique required is high power, there are advantages to running a single ended negative power supply. The negative, single ended supply allows the anode of the tube to be mounted directly to the tube housing which will transfer heat from the anode faster in to the surrounding area.

Conversely, a single ended positive high voltage power supply allows the cathode of the tube to be grounded. This is advantageous because the power supply does not need a high voltage isolation transformer to drive the filament.

Low Filtration
Modern x-ray tubes utilize glass with lower attenuation of x-rays when compared to other glasses. When exposures require lower kV for optimum performance tubes will be designed with a beryllium window. The beryllium window allows lower energy x-rays to pass through when compared to passing through glass. A typical application that utilizes a beryllium window tube is mammography. Breasts are typically x-rayed at kV's between 28 and 32.

Focal Spot Size
Focal spot size is a double edge sword. Generally speaking the smaller the focal spot size the better the resolution. The edge of the sword comes when more power is required. Regardless of the target material, if too much power is applied to the focal spot area of the target, the target it will be destroyed.

There are three areas of the "Maximum Single Exposure Rating" chart that is found in all SXT (Superior X-Ray Tube) data sheets. The left side of the chart is controlled by the instantaneous heating of the surface area of the focal spot on the target face. The center section of the chart is looking at the spot loading and the heat backing up in the body of the anode. The right side of the chart is concerned with the ability of the tube anode to dissipate heat into the high dielectric oil. Concerns of excessive heating of an anode beyond about thirty seconds becomes heavily dependent upon the tube head design and its ability to extract heat from the tube anode. The properties that make high dielectric oil a good electrical insulator unfortunately also make it a good thermal insulator slowing the heat dissipation from the tube housing. Because SXT has no influence on the tube head design, the SXT "Maximum Single Exposure Rating" the SXT chart generally ends at thirty seconds.

Heel Effect
The heel effect is an area of the x-ray beam where the beam intensity is lower. This area is on the anode side of the beam at the outer edge. The effect is caused by photons trying to leave the target that are below the surface of the target. The target absorbs photons more due to the longer angle caused by the depth of penetration. The heel effect area is generally about one to two degrees of the target angle. The effects are typically collimated out of the beam.

Storage capacity of the anode
Storage capacity of an anode, is the amount of energy that can be stored in said anode, in the form of heat. When x-rays, in an x-ray tube, are first turned on, heat migrates through the target material, typically tungsten, and into the surrounding material. In the case of a stationary anode tube, the anode material is almost always copper.

Heat travels through copper much faster than through insulating oil. The properties that make high dielectric oil a good electrical insulator also make it a good thermal insulator. Because of this heat transfer differential, heat begins to back up in the copper of the anode. As the body of the anode begins to heat up, the heat transfer through the copper slows down. If heat backs up too much in the anode, negative things begin to happen.

kV requirements
kV is the electrical potential, delivered across the x-ray tube, by the high voltage power supply. In an x-ray tube, electrons are liberated by a heated filament. The liberated electrons are accelerated across the vacuum gap between the cathode and the anode. The speed at which the electrons travels between the cathode anode gap is proportional to the kV applied across the tube. As the electrons collide with the tungsten target, photons are liberated as x-rays. In general, the higher the kV, the more material the photons can travel through.

mA requirements
Whereas; the kV determines the energy of the electron/photon after the collision. mA refers to the count of said electrons/photons. The higher the mA, the more information, in the form of photons will be delivered the detector.

The size of the object being imaged
One must give careful consideration to the object being viewed via the use of x-rays. A human hand requires much less kV to image when compared to a knee joint. When designing a new x-ray imaging system, one should employ phantoms to verify the techniques used meet health guide lines to insure ALARA (*A*s *L*ow *A*s *R*easonably *A*chievable).

Biasing (applying grid voltage) the beam
Tubes can be designed with a floating filament. For an x-ray tube to function properly, the filament must be referenced electrically, to the focus cup. With this type cathode design, it presents some interesting opportunities. Applying a relative small negative voltage to the focus cup, in reference to the filament, the size of the focal spot can be manipulated. A larger amount of negative voltage applied to the focus cup can be used to pinch the beam off. The latter is referenced as an electronic shutter. The shuttering effect can be synced to the video capture and used to reduce the radiation to the patient (ALARA).

The size of the x-ray detector being used
The size of the detector being used, is an important factor needing study when selecting an x-ray tube. When the detector is set at a fixed distance from the source (x-ray tube), through the use of basic geometry, an optimum target can be considered. As defined previously, one must consider the impact of heel effect on the image. Edges of the affected area of the heel effect can be grossly reduced through the judicial use of a collimator. Match the target angle to the detector size optimizing the efficiency of the x-ray tubes ability to convert electrons to photons delivered to the detector. A mismatch between target angle and detector size causes inefficiencies.

Magnification
Magnification can be a useful tool when viewing an object with fine detail. There are many things to consider when employing magnification in an x-ray imaging system. Here are some aspects I would like to bring up.

When magnification is used, the focal spot size becomes more important. The smaller a focal spot is, the higher the spatial resolution will be. If the detector is not optimized to take advantage of the magnification it will provide no benefit.

If the object being x-rayed is large (say a knee vs a hand), one has to consider the effects of geometric distortion. The side closest to the beam will have more magnification than the side closest to the detector.

One additional consideration is the effect of moving the object, to be imaged, closer to the source. The surface closest to the source will get a much higher entrance dose. X-Rays follow the principle of inverse square law.

Inverse Square Law
The x-ray beam lose intensity in a nonlinear fashion as photons move away from the source. The formula is stated ($1/d^2$) where “d” equals the distance from the source.

Single Spot or Dual Spot
SXT makes stationary tubes with a single spot or a dual spot. The dual spot tubes allow general radiographic on the large spot and the ability to change to a smaller spot in the same tube. The smaller spot giving the ability to increase spatial resolution for a better image.