UNIT I X-RAYS

1.1 NATURE OF X-RAYS

X-rays are electromagnetic radiation located at the low wavelength end of the electromagnetic spectrum. The X-rays in the medical diagnostic region have wavelength of the order of 10 m. They propagate with a speed of 3 × 10 cm/s and are unaffected by electric and magnetic fields. According to the quantum theory, electromagnetic radiation consists of photons, which are conceived as 'packets' of energy.

1.1.1 X-RAY MACHINE

Basically, there are two parts of the circuit. One of them is for producing high voltage, which is applied to the tube's anode and comprises a high voltage step-up transformer followed by rectification. The current through the tube follows the HT pathway and is measured by a mA metre. A kV selector switch facilitates change in voltage between exposures. The voltage is measured with the help of a kV metre. The exposure switch controls the timer and thus the duration of the application of kV. To compensate for mains supply voltage (230 V) variations, a voltage compensator is included in the circuit. The second part of the circuit concerns the control of heating X-ray tube filament. The filament is heated with 6–12 V of AC supply at a current of 3–5 amperes. The filament temperature determines the tube current or mA, and, therefore, the filament temperature control has an attached mA selector. The filament current is controlled by using, in the primary side of the filament transformer, a variable choke or a rheostat. The rheostat provides a stepwise control of mA and is most commonly used in modern machines. A preferred method of providing high voltage DC to the anode of the X-ray tube is by use a bridge rectifier using four valve tubes or solid-state rectifiers. This results in a much more efficient system than the half wave of self-rectification methods. The kV meter is connected across the primary of the HT transformer. It actually measures volts, whereas it is calibrated in kV, by using an appropriate multiplication factor of the turns-ratio of the transformer. In the older types of diagnostic X-ray generators, the kV meters indicated only no load voltage. In order to obtain the load voltage, which varies with the tube current, a suitable kV metre compensation is provided in the circuit. The kV meter compensator is ganged to the mA selector mechanically. Therefore, the mA is selected first and the kV setting is made afterwards during the operation of the machine. Moving coil meters are used for making current (mA) measurements, while for shorter exposures, an mAs meter, which measures the product of mA and time in seconds is used. Moving coil meters have now been generally replaced by digital mA and mAs meters. The basic design of X-ray generators has not changed for the last 50 years. However, there have been considerable developments in the control elements as the demand has grown for increased accuracy, better information display and greater flexibility of selection of factors. The task to be performed by the control circuits of an X-ray generator can well be performed by a microcomputer

Stationary Anode Tube

The normal tube is a vacuum diode in which electrons are generated by thermionic emission from the filament of the tube. The electron stream is electrostatically focused on a target on the anode by means of a suitably shaped cathode cup. The kinetic energy of the electrons impinging on the target is converted into X-rays. Most electrons emitted by the hot filament become current carriers across the tube. It is, therefore, possible to independently set i. Tube current by adjusting the filament temperature, ii. Tube voltage by adjusting primary voltage. Construction of stationary anode X-ray tube Some X-ray tubes function as a triode with a bias voltage applied between the filament and the cathode cup. The bias voltage can be used to control the size and shape of the focal spot by focusing on the electron beam in the tube. The cathode block, which contains the filament, is usually made from nickel or from a form of stainless steel. The filament is a closely wound helix of tungsten wire, about 0.2 mm thick, the helix diameter being about 1.0–1.5 mm. The target is normally comprised a small tablet of tungsten about 15 mm wide, 20 mm long and 3 mm thick soldered into a block of copper. Tungsten is chosen since it combines a high atomic number (74)—making it comparatively efficient in the production of X-rays. It has a high melting point (3400°C) enabling it to withstand the heavy thermal loads. In special cases, molybdenum targets are also used, as in the case of mammography, where in improved subject contrast in the breast is desirable. The lower efficiency of X ray production and the lower melting point make molybdenum unsuitable for general radiography. Copper being an excellent thermal conductor, performs the vital function of carrying the heat rapidly away from the tungsten target. The heat flows through the anode to the outside of the tube, where it is normally removed by convection. Generally, an oil environment is provided for convection current cooling. In addition, the electrodes have open high voltages on them and must be shielded. The tube will emit X-rays in all directions and protection needs to be provided except where the useful beam emerges from the tube. In order to contain the cooling oil and meet the above-mentioned requirements, a metal container is provided for completely surrounding the tube. Such a container is known as a 'shield'. Since a lot of heat will be generated by the tube, and hence this heat will cause the oil temperature to rise, the oil will expand. Being a liquid, oil is incompressible, hence a bellows, either of oil- resistant rubber or thin metal, is provided to accommodate the expansion. Due to the penetrating nature of transformer oil, particularly when it is hot, every joint on a shield has to be hermetically sealed, either soldered or sealed with a rubber gasket. Also, the shield must be made shockproof by an efficient earthing arrangement. Stationary anode tubes are employed mostly in small capacity X-ray machines.

Rotating Anode Tube

With an increasing need in radiology for more penetrating X-rays, requiring higher tube voltages and current, the X-ray tube itself becomes a limiting factor in the output of the system. This is primarily due to the heat generated at the anode. The heat capacity of the anode is a function of the focal spot area. Therefore, the absorbed power can be increased if the effective area of the focal spot can be increased. This is accomplished by the rotating anode type of X-ray tubes. The tubes with rotating anode are based on the removal of the target from the electron beam before it reaches too high a temperature under the electron bombardment and the rapid replacement of it by another cooler target. The anode is a disk of tungsten or an alloy of tungsten and 10% rhenium. This alloy helps to reduce the changes in the anode track due to stress produced in the track as a result of the rapidly changing temperature. The anode rotates at a speed of 3000–3600 or 9000–10000 rpm. The tungsten disk that represents the anode has a bevelled edge that may vary from 5°–20°. Typical angles are around 15°, in keeping with the line focus principle. These design elements help to limit the power density incident on the physical focal spot while creating a small effective focal spot. With the rotating anode, the heat produced during an exposure is spread over a large area of the anode, thereby increasing the heat-loading capacity of the tube and allowing higher power levels to be used which produces more intense x-radiation. The rotor is made from copper, either cast or from special quality rod. The molybdenum stem projecting from the rotor is either soldered or the copper of the rotor may be cast round it. The choice of molybdenum is dictated by the need for a strong metal with a melting point high enough to permit contact with a very hot tungsten disk. The anode rotation system is a high speed system. Therefore, the bearings must be properly lubricated. The high temperature environment inside the tube precludes most normal lubricants, that would have the additional disadvantage of releasing enough vapour to spoil the condition of high vacuum, which is necessary for the proper functioning of the tube. The situation has been remedied by the successful development of metal lubricants. The commonly used lubricants are lead, gold, graphite or silver. These lubricants are usually applied to the bearing surfaces in the form of a thin film (Hill, 1979). The tube housing serves several technical purposes. It is a part of the electrical isolation between the high voltage circuits and the environment. The housing is lead-lined to keep the amount of leakage radiation below legal levels, thereby providing radiation protection for both the patient and the operator. Finally, the tube housing is an important part of the waste-heat handling system. While housings for tubes used at low mean power levels can be adequately air-cooled, it becomes necessary to provide additional cooling in case of higher power levels, which is done by circulating water through a heat exchanger contained in the tube housing or by circulating insulating oil through an external radiator. Geldner (1981) discusses electrical, thermal and load characteristics of rotating anode X-ray tubes. Homberg and Koppel (1997) illustrate a spiral groove bearing which has several advantages over conventional anode ball bearing used in heavy duty X-ray tube assemblies. Apart from being quiet in operation, the spiral groove bearing technology permits extremely efficient cooling of the anode dish by conducting heat away into a cooling medium. This prolongs the life, even though the anode disk is operated continuously at a high speed of rotation. X-ray tubes are further classified on the basis of their application for diagnostic or therapeutic purposes. For diagnostic applications, it is usual to employ high milliamperes and lower exposure time whereas high kV and relatively lower mA are necessary for therapeutic uses. The description which follows relates only to the diagnostic X-ray machines.

Collimators and Grids

In order to increase the image contrast and to reduce the dose to the patient, the X-ray beam must be limited to the area of interest. Two types of devices are used for this purpose, viz. collimators and grids. It consists of a sheet of lead with a circular or rectangular hole of suitable size. Alternatively, it may consist of four adjustable lead strips which can be moved relative to each other. In practice, it is advisable to use the smallest possible field size. This results in a low dose to the patient and simultaneously increases the image contrast, because less scattered radiation reaches the image plane. The scattered radiation produces diffuse illumination and fogging of the image without increasing its information content, and therefore, by choosing the smallest possible field size and using a collimator, the loss of contrast due to scattered radiation is reduced. This can be projected on the patient to ensure proper positioning of the apparatus.

Grids are inserted between the patient and the film cassette A grid consists of thin lead strips separated by spacers of a low attenuation material. The lead strips are so designed that the primary radiation from the X-ray focus, which carries the information, can pass between them while the scattered radiation from the object is largely attenuated. The focal radiation from the X-ray tube can pass between the lead stripes, whereas much of the scattered radiation from the object is cut off because of its direction Because of the shadow cast by the lead strips, the final image is striped. These grid lines do not usually interfere with the interpretation of the image. However, final details in the image may be concealed. In order to avoid this, the grid can be displaced during the exposure so that the lead strips are not reproduced in the image. Such moving grids are known as 'Bucky Grids'