Radiography Machine, Analog

Purpose

Diagnostic X-rays is a painless, noninvasive way to help diagnose problems such as broken bones, tumours, dental decay, and the presence of foreign bodies. It is typically an X-ray film based system that uses analog techniques for image capture and display.

الأشعة السينية التشخيصية هي طريقة غير مؤلمة وغير جراحية للمساعدة في تشخيص مشاكل مثل العظام المكسورة والأورام وتسوس الأسنان ووجود أجسام غريبة. وهي عبارة عن نظام يعتمد على فيلم الأشعة السينية يستخدم تقنيات تناظرية لالتقاط الصور وعرضها.

Principle

Radiography is the use of X-rays to visualize the internal structures of a patient. X-rays are a form of electromagnetic radiation, produced by an X-ray tube. Diagnostic X-ray images are produced by positioning the part of the body to be examined between a focused beam of X-rays and a plate containing the film sensitive to X-rays. X-rays pass easily through air and soft tissue of the body, but when they encounter denser material, such as a tumor, bone, or metal fragment, the more X-rays are absorbed. The X-rays that pass through the body are captured behind the patient by the film. Due to variance in the absorption of the X-rays by different tissues within the body, an image is produced to give a 2D representation of all the structures within the patient's body.

X-rays were accidentally discovered in 1895 by German physicist Wilhelm Roentgen(1845-1923), who was later awarded the first Nobel Prize in physics for his discovery. His first X-ray picture was of his wife's hand. Within a few years, X-rays became a valued diagnostic tool of physicians worldwide. A general-purpose stationary diagnostic X-ray system can be used in a variety of routine planar X-ray imaging applications. The stationary design requires it to be installed and used in a fixed location within a building or in a transportation van for mobile imaging facility. This generic device group does not cover systems with fluoroscopic or tomographic capabilities.

Components of the X-ray System

The major components of a general purpose X-ray system are the following:

1-

a- X-ray tube, b- X-ray generator, c- tube stand or support, d- examination table, e- control unit

2- Accessories such as cassettes, intensifying screens, films, etc.

block diagram of basic X-ray

Figure.1 shows a block diagram of basic X-ray machine subsystems. 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 an 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

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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 A. 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.

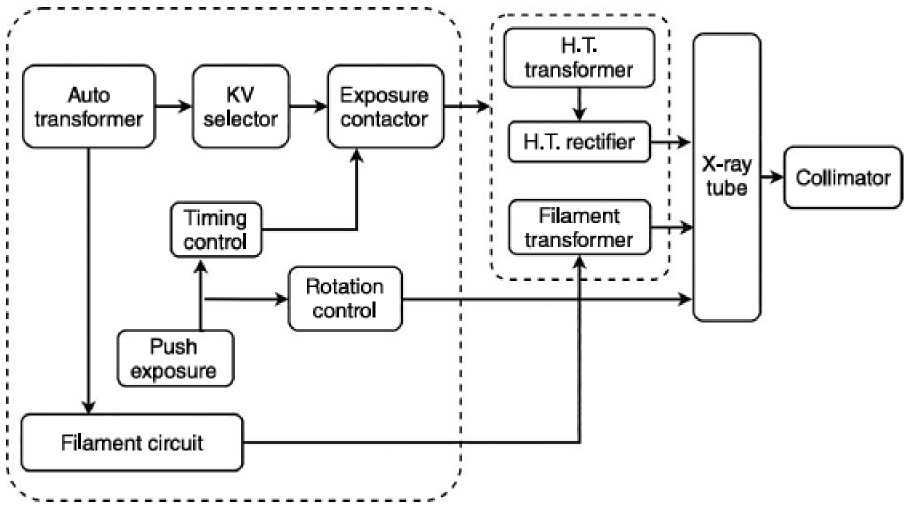

Figure 1 Block diagram of an X-ray machine.

A preferred method of providing high voltage DC to the anode of the X-ray tube is by using 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 metre 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 metres indicated only no-load voltage. In order to obtain the load volt age, which varies with the tube current, a suitable kV metre compensation is provided in the circuit. The kV metre compensator is ganged to

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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 metres are used for making current (mA) measurements, while for shorter exposures, an mAs metre, which measures the product of mA and time in seconds, is used. Moving coil metres have now been generally replaced by digital mA and mAs metres. 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.

X-ray Tube

The X-rays are produced in specially designed X-ray tube. In all X-ray tubes, the electrons are produced by a cathode, which is a heated filament of tungsten wire. The electrons bombard the anode under the influence of the high voltage between the cathode and the anode. The area of the anode where the electrons strike is called the focal spot. Stationary mode tubes and rotating anode tubes are the two main types of X-ray tubes.

Stationary Tube

In the stationary tube, the anode and the cathode are sealed into a glass envelope (tube) in a vacuum. The glass X-ray tube is enclosed in a casing made of aluminium and lined with thin sheets of lead to prevent leakage of radiation. The metal case provides protection to the tube from mechanical shock and protects the users from radiation and electrical shock. The X-rays leave the tube through a plastic covered window. 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 of 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℃) enabling it to withstand the heavy thermal loads. In special cases, molybdenum targets are also used, as in the case of mammography, wherein 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. 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 construction of a typical rotating anode X-ray tube is shown in Figure 314.2. The anode is a disc 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 or9000-10 000 rpm. The tungsten disc that represents the anode has a beveled edge that may vary from 5º-20º. Typical angles are around 15e, in keeping with the line focus principle. These design elements help to limit the power density incident on the physi- cal focal spot while creating a small effective focal spot. With the rotating

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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. Either the molybdenum stem projecting from the rotor is 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 disc. The anode rotation system is a high speed system. Therefore, the bearings must be properly lubricated. 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.

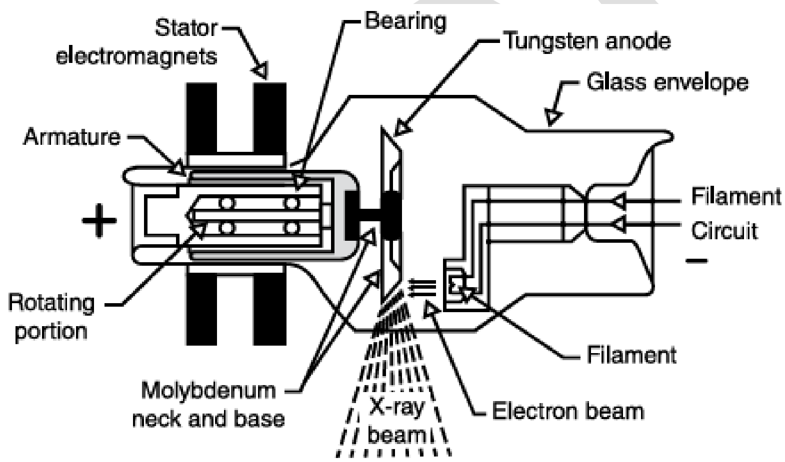

Figure .2 Constructional details of a rotating anode X-ray tube.

X-ray Generator

The purpose of the X-ray generator is to provide the high voltage DC that is applied to the X-ray tube for production of X-rays. There are several types of generators that are available in practice. They may use single phase or three phase power supply and convert it to DC voltage. However, most modern generators are based on generators can operate up to 100kHz, although most systems will operate below frequency converter and multipulse operation. Current high frequency50

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kHz. If maximum frequency is below 20kHz, the generator is called 'medium frequency' generator. These generators are less bulky and much lighter and produce high quality X-ray beam. Basically, in the high frequency generator, the AC mains power is rectified, and smoothed by a large value capacitor, to get DC voltage supply. The 'inverter' converts the DC voltage back into a high frequency AC voltage. This in turn is fed into primary winding, of the high-tension transformer. The high-tension transformer uses ferrite instead of an iron core, which gives higher efficiency. High voltage output is highly regulated, so normal changes in power main voltages have no effect on the exposure. A high frequency generator waveform has less ripple, in many cases less than 2%. When used in a mobile system, the inverter may operate directly from storage batteries, or else from large capacitors charged via the power point. Figure.3 shows the circuit diagram of a high frequency generator. It makes use of an inverter to convert DC voltage to AC voltage. The output of this inverter is coupled via a resonant circuit to the primary of the HT transformer. The resonant circuit has two functions. (i) As the pulse rate of the inverter increases towards resonance, the energy each pulse produces in the HT transformer secondary also increases. This allows a very wide range of control of output power. (ii) The resonant circuit has a 'flywheel effect', so that on the reverse half cycle, the back electro- motive force attempts to reverse the current in the input circuit that produced the initial pulse. The high-tension transformer is operated similar to a single-phase generator. For medium frequency generators, capacitors are added to provide wave- form smoothing. For many high frequency generators, however, the inherent capac- itance of the HT cables provides the required smoothing, without added capacitors. A built-in resistive voltage divider provides measurement of the high voltage during the exposure. This measurement is compared with a reference voltage equivalent to that for the required kV. If there is any difference, the inverter control circuit changes the pulse

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rate to correct the error. An X-ray generator usually has a number of fuses, of different ratings and types, to safeguard the various circuits and their components.

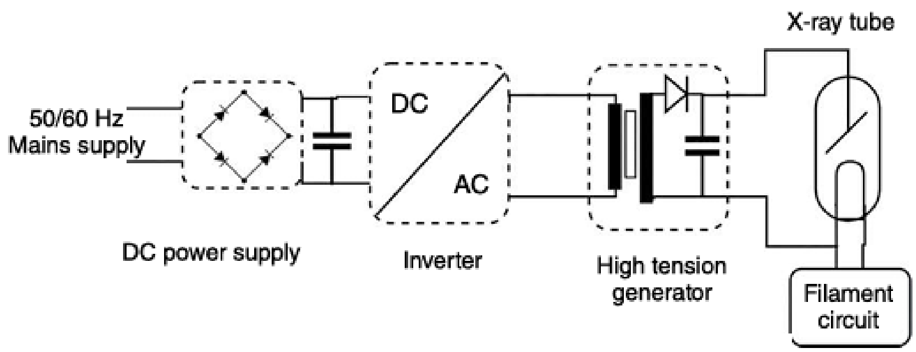

Figure .3 Principle of a high frequency, high-tension generator.

Tube Stand/Tube Support/Tube Column

A typical X-ray machine is shown in Figure 314.4. The function of the tube stand is to support the X-ray tube so that it can be used with the X-ray beam in a horizontal or vertical position or at an angle. There are several types of tube support structures. It could be a simple column mounted on floor rails or integrated with the control unit and the transformer or a column forming an integral part of the X-ray table. Alternatively, it could be a fixed column with a tube rotating around a central axis. This is usually referred to as 'C' arm type and is used for WHO Basic Radiological System.

Grid

When an X-ray beam passes through a patient, some of the X-rays continue in a straight line, while some of it can get scattered in different directions. If the scattered X-rays reach the film, it will result in distorted and spoiled image. The function of the grid (metal screen) is to absorb the scattered radiation. For this reason, it is often called'anti-scatter grid. The grid may be stationary or it may be incorporated in a bucky mechanism, which makes the grid move during exposure.

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Grids are delicate and, therefore, are supplied either coated in plastic for protection or as an integral part of a cassette.

Figure .4 Typical radiography machine. *Source:* Image courtesy of M/s Siemens Healthineers.

Patient Table

The patient table provides support to the patient when the patient is lying on it for examination. The table is approximately 2.0 m x 0.65 m in size and about0.7 m from the floor. It must be rigid with a capacity to support patient weighing 120 kg without appreciable distortion. The tabletop should be permeable to X-rays, impervious to fluids and resistant to scratching. It may incorporate a bucky with a grid.

Chest Stand

The chest stand is a holder for cassettes that is used to examine patients in the erect position for chest or other radiography. It may incorporate an anti-scatter grid and should be able to hold cassettes either in front or behind it. In some units, it is possible to orient the cassette at an angle to the vertical. The stand should be

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adjustable in height, strong, and rigid. Control Unit The X-ray control unit provides kV selection, mA output, and exposure time. The control unit displays the value of various parameters that are selected for taking X-ray. These include metres or digital indicators to show the status of mains power supply, the kV and mAs, and exposure switch. Mostly, the control unit is located outside the X-ray room. A lead glass window is generally provided so that the patient can be watched during examination.

Cassettes and Intensifying Screens

Cassettes are light proof and rigid containers that enclose the X-ray film. Within the cassette are two intensifying screens that fluoresce and produce visible light when irradiated by X-rays. The film is placed between the two intensifying screens. The cassette must provide firm pressure so that there is good contact between the film and the screens. In addition, there is dark room equipment and other materials for processing the exposed film and radiation protection devices such as lead apron and film badges. Contrast Material Sometimes a liquid called contrast material, for example, barium, is used to help outline internal organs such as the intestines. The contrast material absorbs X-rays, helping to make soft tissue more easily visible on the X-ray films. Contrast material is commonly used in making X-rays of the digestive system. The contrast liquid can be swallowed or injected, depending on the part of the body being X-rayed.

Specifications

1- kV range: 50-150 kV, digitally displayed
2- mA range: 0-600 mA
3- Exposure time range: 1 ms-5s (automatic exposure control facility)
4- Resolution: 5 line pairs/mm
5- Focal spot size: Less than 1 mm
6- Adjustable multileaf collimator, rotatable +90º with patient centering light
7- Source to image distance range: 90-125 cm
8- Patient table: Motorized tilt from at least +90º to -15º
9- Patient table longitudinal and lateral movements: At least 160 and 20 cm, respectively
10- Patient table vertical movement: From 60 to 120 cm from ground.

Applications

X-ray machines are widely used in healthcare facilities at all levels - health centre, district hospital, provincial hospital, specialized hospital, and radiology practice centres. They find applications in radiology department, orthopaedics, emergency room, etc. The common clinical applications include radiography of chest (to assess lung pathology), skeletal (to examine bone structure and diagnose fractures, dislocation, or other bone pathology), and abdomen to assess abdominal obstruction, free air, or free fluid within the abdominal cavity.

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