CT System Design

The basic equipment configuration for CT represented by ***three major systems each of them housed in separate rooms***, as follows:

1) The imaging system is located in the ***scanner room***.
2) The computer system is located in the ***computer room***.
3) The display, recording, storage and communication systems are located in the ***operator's room***.

Today, CT scanners are typically housed in similar physical spaces that contain the three system components identified in Figure 1.

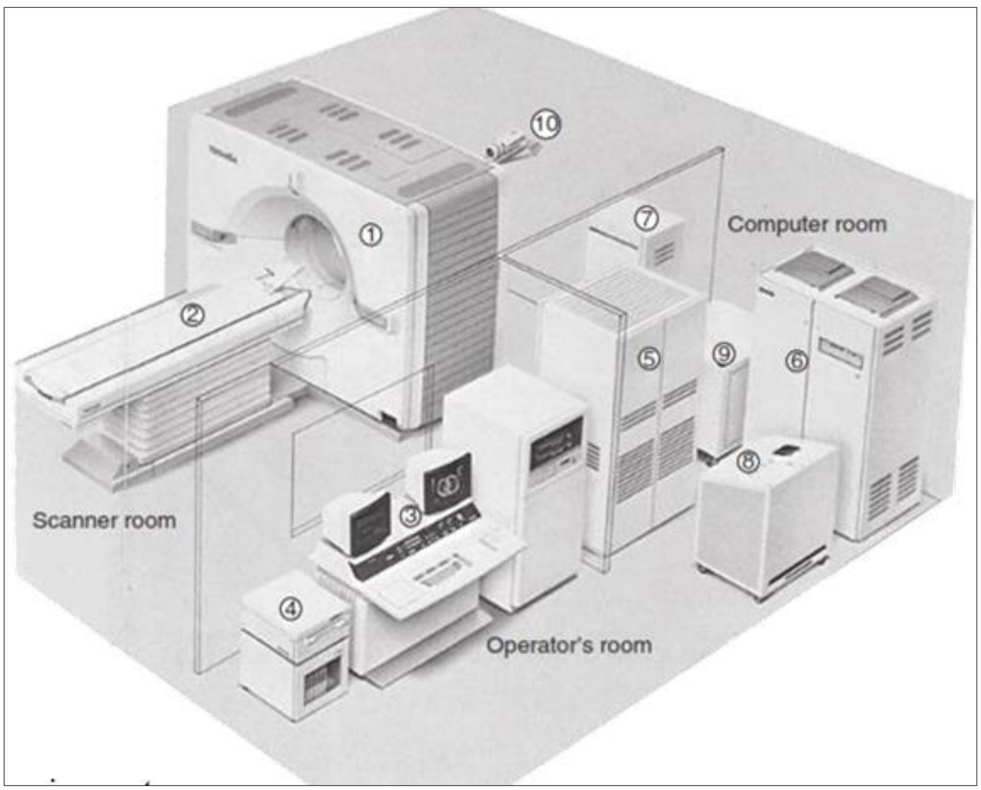

Fig.1 Components of a CT imaging system.

(1) Gantry; (2) patient couch; (3) integrated console; (4) optical disk system including cassette storage; (5) high-speed processor system; (6) X-ray high-voltage generator; (7) couch control unit; (8) system transformer I; (9) system transformer II; (10) patient observation system.

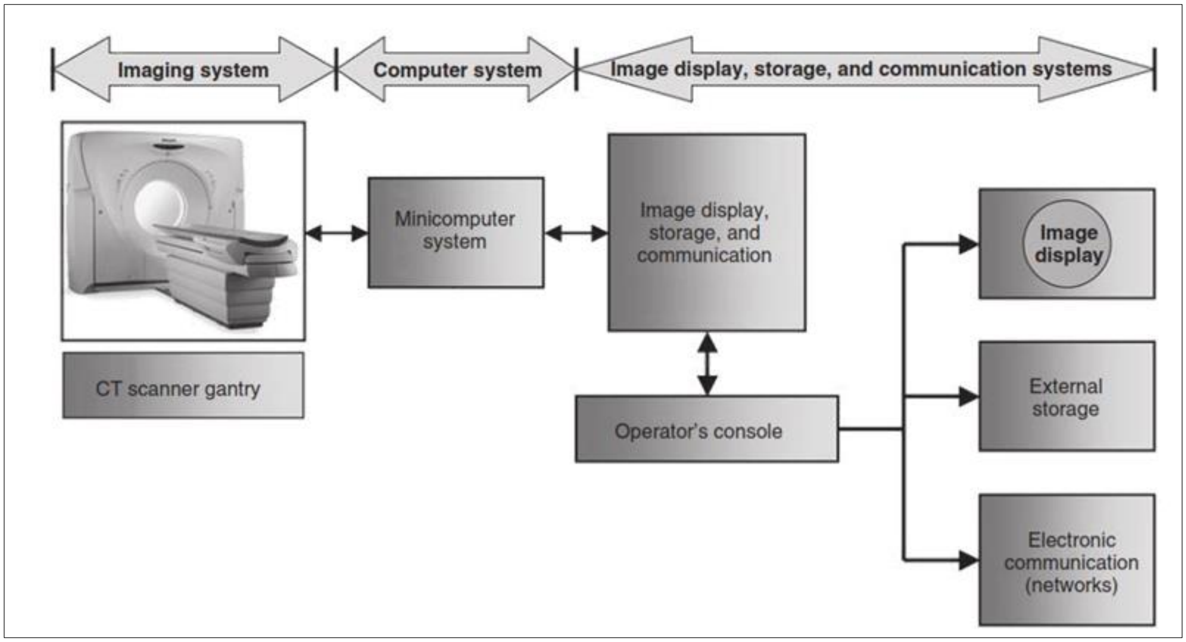

Fig 2: Basic equipment configuration for CT, the major technical components.

The imaging system

The purpose of the imaging system is to:

- Produce X-rays, shape and filter the X-ray beam to pass through only a defined cross section of the patient,
- Detect and measure the radiation passing through the cross section,
- Convert the transmitted photons into digital information.

The major component of the imaging system is the ***gantry*** that comprises several components housed in it, represented by; the ***X-ray tube*** and ***generator***, ***collimators***, ***filter***, ***detectors***, and ***detector electronics***.

The ***X-ray tube and generator*** are responsible for ***X-ray production***. The radiation beam that emanates from the tube is ***filtered through a specially designed filter*** that ***protects the patient from low-energy rays and ensures beam uniformity at the detectors***.

The ***collimators*** help ***define the slice thickness and restrict the X-ray beam to the cross section of interest***.

The ***detectors capture the X-ray photons and convert them into electrical signals*** (analog information).

The ***detector electronics***, or data acquisition system (DAS), ***converts this information into digital data***.

Gantry

The gantry assembly is the ***largest*** of these systems. It is a ***rotating mounted scan frame that surrounds the patient in a vertical plane***.

Two important features of the gantry are the ***gantry aperture*** and the ***gantry tilting range***. The ***gantry aperture*** is the ***opening*** in which the patient is positioned during the scanning procedure. The technologist can ***approach the patient from both the front and back of the gantry***. Most scanners have a ***70-cm aperture*** that facilitates patient positioning and helps provide access to patients in emergency situations.

The CT gantry must be capable of ***tilting*** (Fig.3) ***to accommodate all patients and clinical examinations***. The degree of tilt ***varies*** between systems, but ***±12 to ±30 degrees*** in ***0.5-degree increments*** is somewhat standard.

Fig.3: the gantry tilting

The gantry also includes three set of laser beams to aid patient positioning which are:

- Internal laser
- Wall-mounted laser
- Overhead laser

When lasers are positioned ***at zero setting***, their i***ntersection point is coincident with the center of the scan plane***.

A) Internal laser

- All scanners contain an internal laser to identify ***the scan plane***.
- This internal laser is mounted at the scanner bore of the CT scan machine.
- This type of laser used to mark the patient during the scan and treatment process.

B) Wall-mounted laser

These types of laser usually situated at ***the right and left of the room to align the patient and the couch***.

C) Overhead Laser

- These lasers also have the same function ***as wall-mounted laser*** which is used to ***mark the patient***. It may ***represent isocenter, field corners or markers***.
- It is projecting at the same fixed distance as lateral laser but orthogonal to scan plane.
- These lasers are always capable of lateral movement because scanner couch may not.

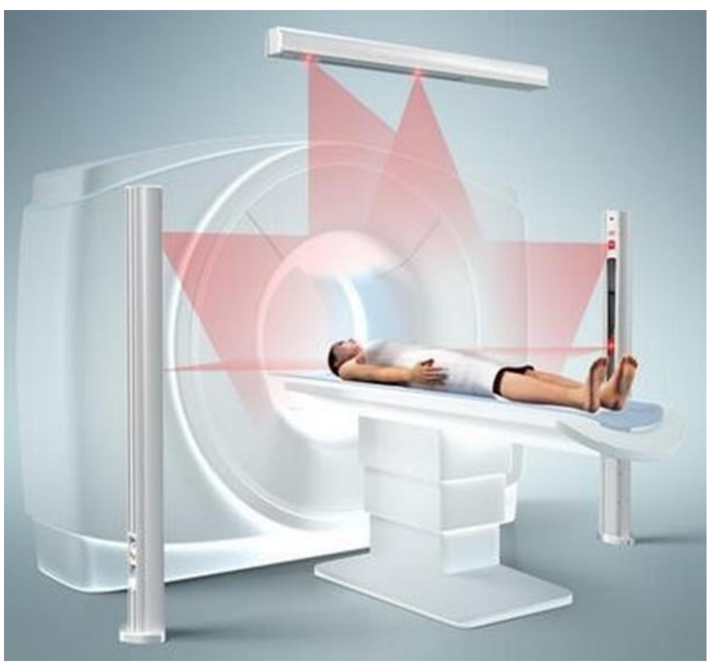

Fig.4: Types of lasers used in the CT Scan

The essential parts of the gantry include:

- high-voltage generator
- X-ray tube,
- X-ray beam filters
- collimators
- detector array

X-ray system

- patient support couch,
- slip rings
- DAS
- Mechanical support for each.

These subsystems ***receive electronic commands from the operating console*** and ***transmit data to the computer*** for image ***production and post-processing tasks***.

High-voltage Generator

Previously, CT scanners use ***three-phase power*** for the ***efficient production*** of X-rays, but now use ***high-frequency generators***, which are ***small, compact, and more efficient*** than conventional generators. These generators are ***located inside the CT gantry***. In some scanners, the high-frequency generator is ***mounted on the rotating frame with the X-ray tube***; in others it is located in a ***corner of the gantry*** and does ***not rotate*** with the tube.

In a ***high-frequency generator*** (Fig.5), the circuit is usually referred to as a ***high-frequency inverter circuit***.

The ***low-voltage, low-frequency AC current*** (60Hz) from the main power supply is converted to ***high- voltage, high-frequency DC current*** (500 to 25,000 Hz) of almost constant potential as it passes through the components, Fig. 5. After high-voltage rectification and smoothing, the voltage ripple from a high-frequency generator is less than 1%. This makes the high- frequency generator more efficient for X-ray production.

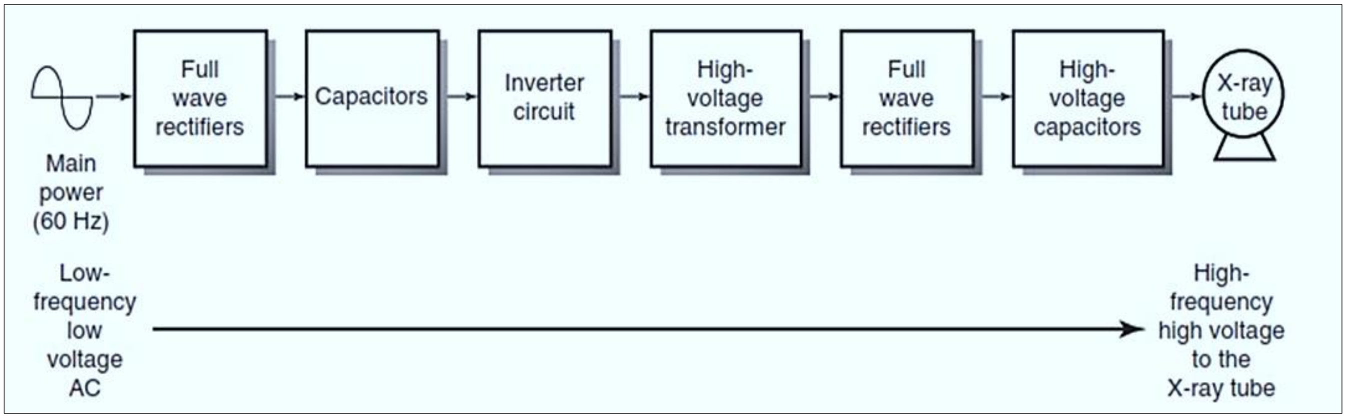

Fig. 5: Basic components of high-frequency generator used in modern CT scanners

The ***X-ray exposure*** technique obtained from these generators ***depends on the generator power output***. The ***power ratings of CT generators vary and depend on the CT vendor***; however, ***typical ratings can range from 20 to 100 kilowatts (kW)***. More recently CT manufacturers have generators capable of ***120 kW***. An output capacity of, say, ***60 kW will provide a range of kilovolt and milliampere settings***, where 80 and 120 to 140 kV and 20 to 500 milliamperes (mA) are typical.

X-Ray Tubes

The radiation source requirement in CT depends on two factors:

1) ***Radiation attenuation***, which is a function of radiation ***beam energy, the atomic number and density of the absorber, and the thickness of the object.***
2) ***Quantity of radiation*** required for ***transmission***. X-ray tubes satisfy this requirement.

Rotating anode X-ray tubes have become common in CT because of the demand for ***increased output***. The rotating anode tubes, Fig. 6, have ***large-diameter anode disk*** to ***facilitate the spatial resolution requirements of the scanner***. The disk is usually made of ***a rhenium, tungsten, and molybdenum (RTM) alloy*** and other materials with ***a small target angle (usually 12 degrees) and a rotation speed of 3600 revolutions per minute (rpm) to 10,000 rpm (high-speed rotation)***. Fig.6, B, shows an upgraded tube based on the technology used in the tube shown in Fig.6, A.

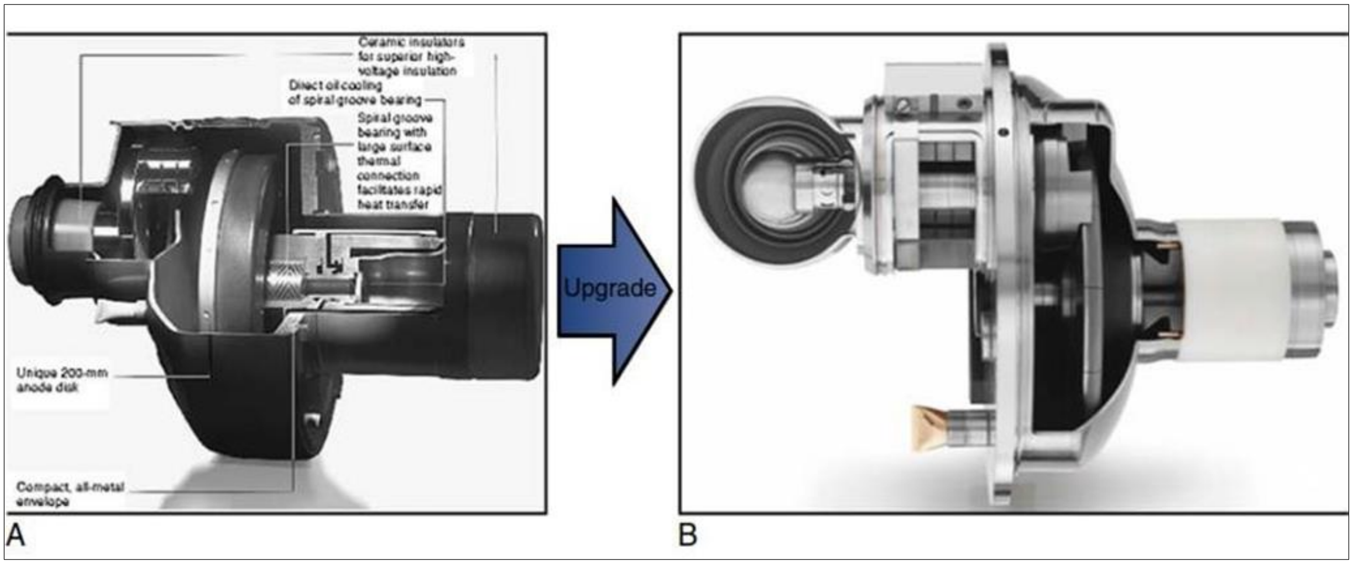

Fig. 6: A modern rotating anode X-ray tube used in CT scanners. The tube shown in (B) is an upgraded tube based on the technology used in the tube shown in (A). (A, Courtesy Philips Medical Systems, Shelton, Conn; B, Courtesy Philips Healthcare)

The introduction of ***spiral/helical CT*** with continuous rotation scanners has ***placed new demands on X-ray tubes***. Because the tube ***rotates continuously for a longer period***, the tube must be able to ***sustain higher power levels***. Several technical advances in component design have been made to ***achieve these power levels and deal with the problems of heat generation, heat storage, and heat dissipation.*** For example, ***the tube envelope, cathode assembly, anode assembly including anode rotation, and target*** have been redesigned.

The ***glass envelope*** ensures a ***vacuum***, provides ***structural support*** of anode and cathode structures, and provides ***high-voltage insulation*** between the anode and cathode. Although the ***borosilicate glass provides good thermal and electrical insulation, electrical arcing results from tungsten deposits on the glass caused by vaporization***. Tubes with ***metal envelopes***, which are now common, solve this problem.

Metal envelope tubes have ***larger anode disks***; for example, the tube shown in Figure (6) has a ***disk with a 200-mm diameter*** compared with the ***120- to 160-mm diameter*** typical of ***conventional tubes***. This feature allows the technologist to use ***higher tube currents***. ***Heat-storage capacity*** is also increased with an ***improvement in heat dissipation rates***.

The ***cathode assembly*** consists of ***one or more tungsten filaments*** positioned in a ***focusing cup***.

The ***anode assembly consists of the disk, rotor, hub, and bearing assembly***. ***Larger and thicker anode disk*** than conventional disks are used; there are three basic designs (Fig.7):

- ❖ The conventional all-metal disk,
- ❖ The brazed graphite disk,
- ❖ The chemical vapor deposition (CVD) graphite disk.

In ***conventional tubes***, the ***all-metal disk*** (Fig.7, A) consists of a base body made of ***titanium, zirconium, and molybdenum (TZM)*** with a ***focal track layer of 10% rhenium and 90% tungsten***. It can ***transfer heat from the focal track very quickly***. Unfortunately, tubes with this all-metal design ***cannot meet the needs of spiral/helical CT imaging because of their weight***.

The ***brazed graphite*** anode disk (Fig. 7, B) consists of a ***tungsten-rhenium focal track brazed to a graphite base body***. ***Graphite increases the heat- storage capacity*** because of its high thermal capacity, which is about ***10 times that of tungsten***. The material used in the ***brazing process influences the operating temperature of the tube***, and the higher ***temperatures result in higher heat-storage capacities and faster cooling of the anode***. Tubes for ***spiral/helical CT scanning are based mostly on this type of design***.

The ***brazing process*** is a metal-joining process in which ***two or more metal items are joined together*** by melting and flowing a filler metal into the joint, with the ***filler metal having a lower melting point than the adjoining metal***.

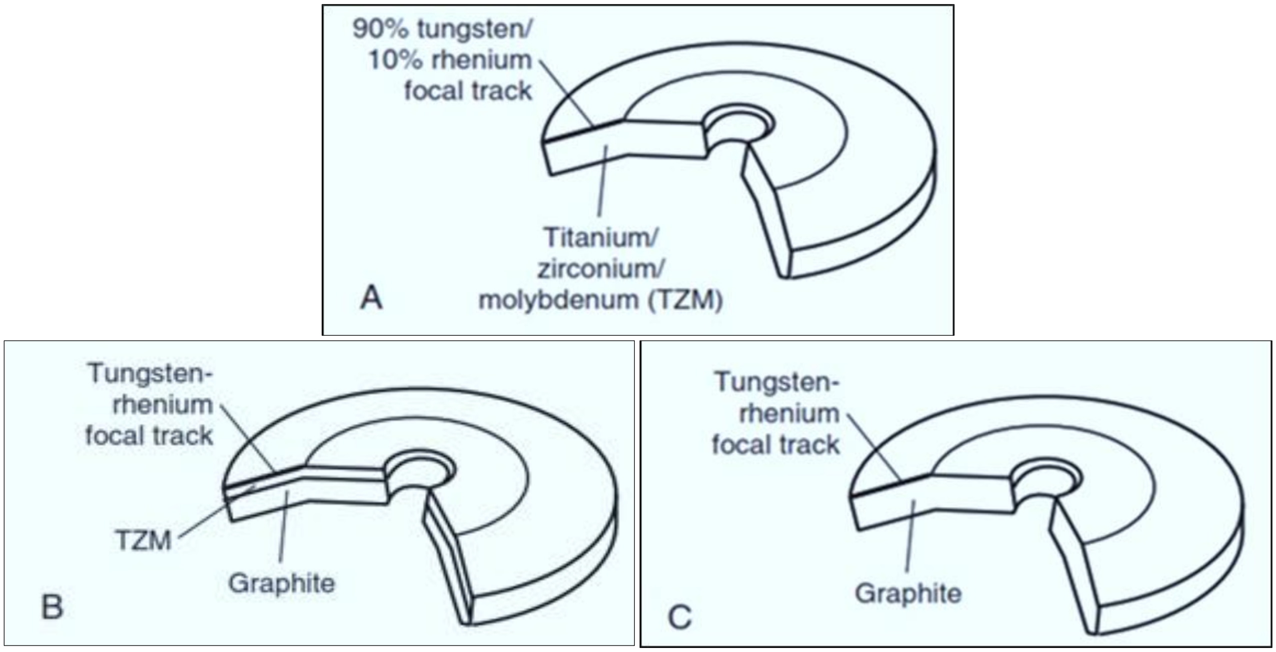

Fig.7: Three types of disk designs for X-ray tubes in CT scanners: (A) conventional all-metal disk; (B) brazed graphite anode disk; and (C) CVD graphite anode disk

The final type of anode design (Fig. 7, C) is also intended for ***use in spiral/helical CT X-ray tubes***. The ***disk consists of a graphite base body with a tungsten-rhenium layer deposited on the focal track by a chemical vapor process***. This design can accommodate ***large, lightweight disks with large heat-storage capacity and fast cooling rates***.

The purpose of the bearing assembly is to provide and ensure smooth rotation of the anode disk. In modern CT, ***smooth rotation of the disk is improved by using a liquid-bearing method*** (Fig. 8). The stationary shaft of the anode assembly consists of ***grooves that contain gallium-based liquid metal alloy***. During anode rotation, the ***liquid is forced into the grooves and results in a hydroplaning effect*** between the anode sleeve and liquid.

The ***purpose of this bearing*** technology is ***to conduct heat*** away from the X-ray tube ***more efficiently*** than conventional ball bearings with ***improved tube cooling***. Additionally, the ***liquid-bearing technology is free of vibrations and noise***.

The working life of the tubes can range from about 10,000 to 40,000 hours, compared with 1000 hours, which is typical of conventional tubes.

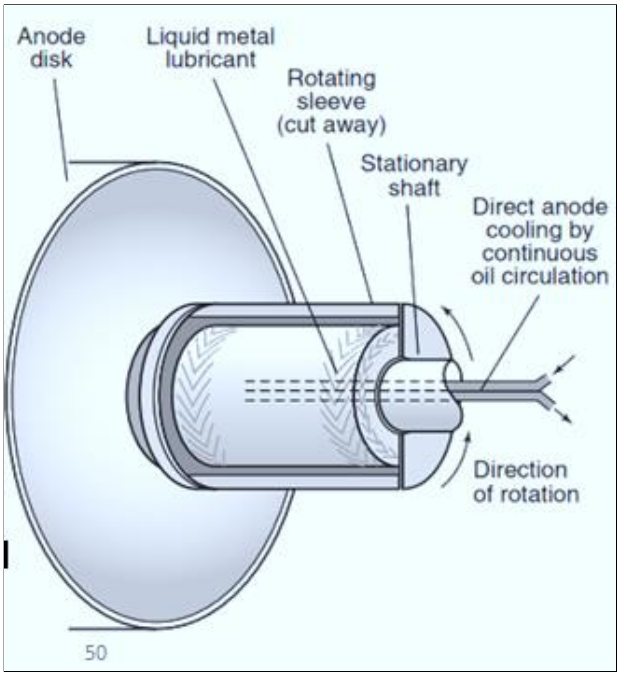

Fig.8: Anode assembly of modern X-ray tube used in CT. Main parts of assembly are the <u>disk</u>, <u>rotor</u>, and <u>bearing assembly</u> that contains <u>liquid metal lubricant</u>.

<u>**Straton X-Ray Tube: A New X-Ray Tube for MSCT Scanning**</u>

The fundamental problem with conventional X-ray tubes is the heat dissipation and slow cooling rates. Efforts have been made to deal with these problems by introducing various designs, such as ***large anode disks*** and ***the introduction of the compound anode design*** (RTM disk), which has ***higher heat- storage capacities and cooling rates***. Additionally, as ***gantry rotation times increase, higher milliampere values are needed to provide the same milliamperes per rotation***. As the ***electrical load (milliamperes and kilovolts) increases, faster anode cooling rates are needed***.

Despite these efforts, ***the problems of heat transfer and slow cooling rates still persist with MSCT scanners***. To overcome these problems, a new type of X-ray tube called ***Straton X-ray tube has been introduced for use with MSCT scanners***. This unique and revolutionary tube was designed by ***Siemens Medical Solutions*** (Siemens AG Medical Solutions, Erlangen, Germany).

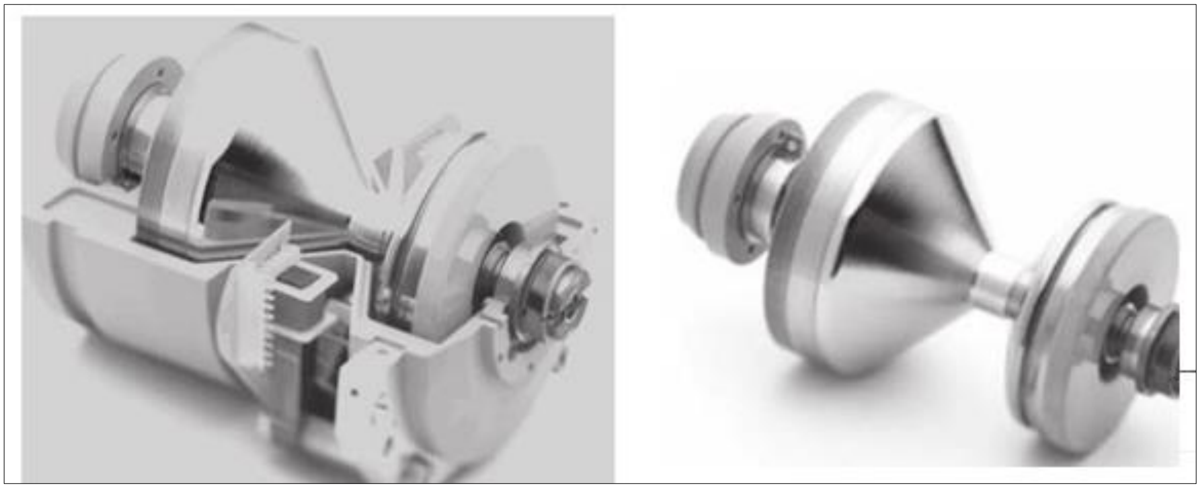

Fig.9: The Straton X-ray tube, a new x-ray tube for MSCT scans.

The Straton X-ray tube (Fig.9) is compact in design to much ***smaller than conventional X-ray tubes*** described earlier. This size ensures a ***fast gantry rotation of 0.37 seconds***.

The Straton X-ray tube is encased in a ***protective housing that contains oil for cooling***, and the ***motor provides a rotation of the entire tube*** (which is immersed in oil). It is important to note that the ***anode is in direct contact with the oil*** (directly cooled tube). Because the ***anode is in direct contact with the circulating oil, very high cooling rates will result***, as illustrated in Fig.10.

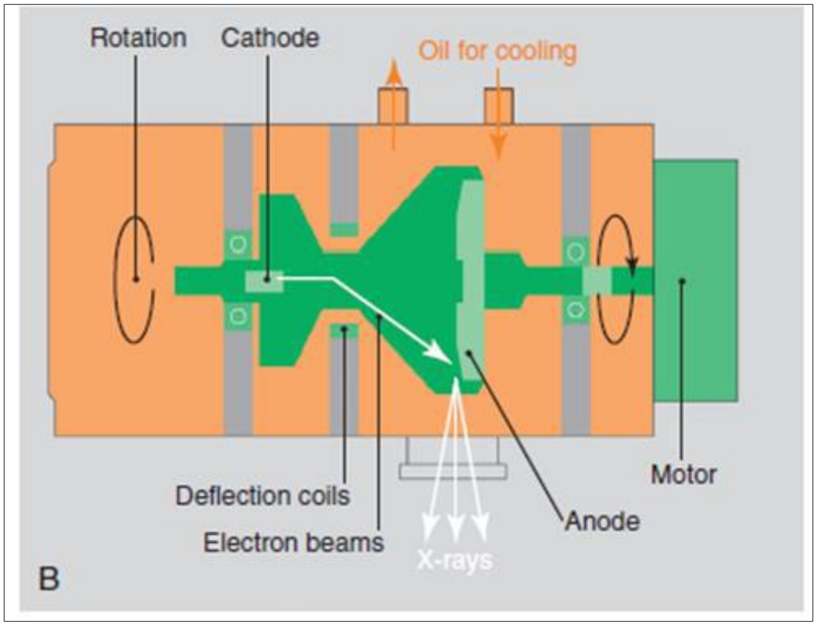

Fig. 10: Straton X-ray tube.

This diagram shows the anode and cathode structures, deflection coils, an electron beam, and a motor.

Another important feature of the Straton X-ray tube related to the electron beam from the cathode. The beam is deflected to strike the anode at ***two precisely located focal spots*** (Fig.11) that vary in size; ***1.1 mm, and 0.7 mm***. The electron beam alternates at about ***4640 times per second to create two separate X-ray beams that pass through the patient and fall on the detectors***.

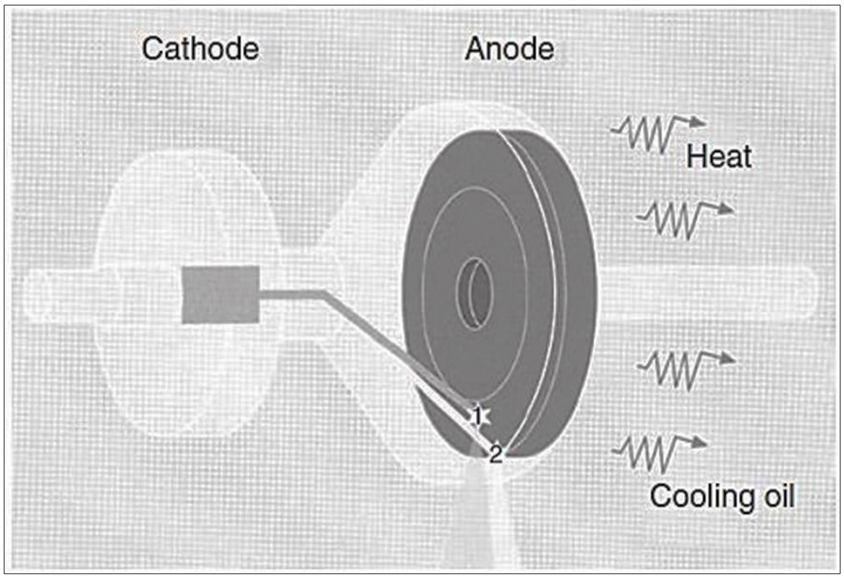

Fig. 11: An important feature of the Straton X- ray tube is that the electron beam from the cathode is deflected to strike the anode at two precisely located focal spots that vary in size.

The Advantages of Straton X-ray tubes

1) Better heat dissipation
2) Various size multiple focal spot
3) Longer tube life
4) High-speed volume scanning is possible
5) Can be used in high kV and high mA technique for prolonged duration. Ie; (High mAs & long exposure times for increasing lengths of anatomic coverage).