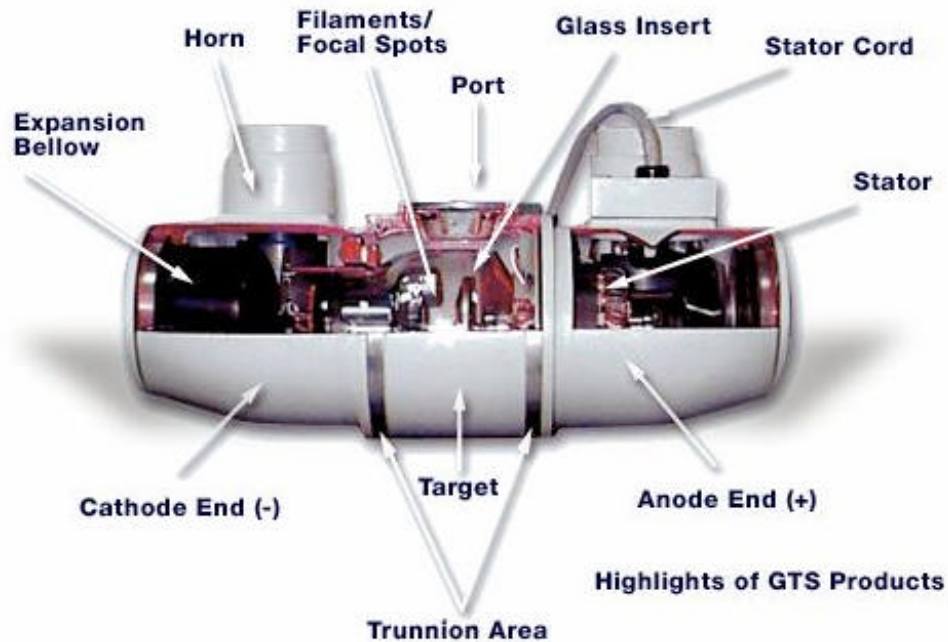
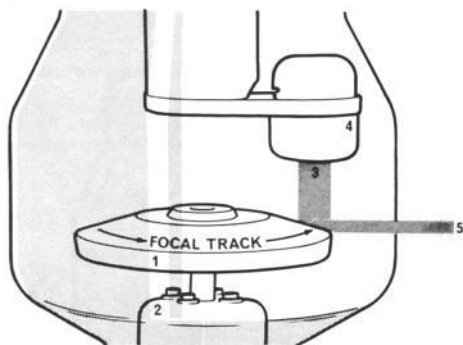


The Rotating Anode X-Ray Tube



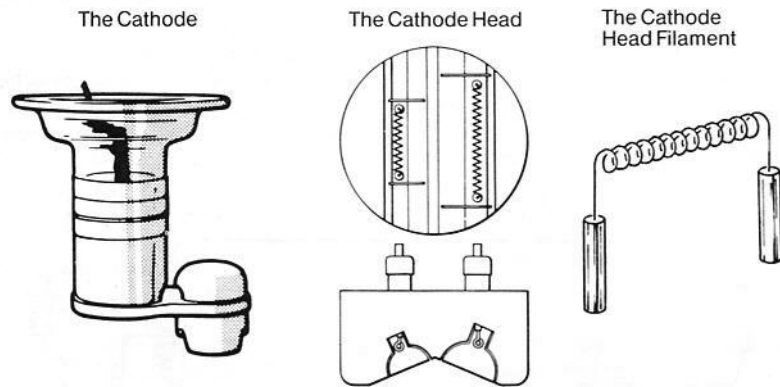
The rotating Anode tube assembly is a complex piece of electro-mechanical engineering comprising of around 350 parts taking 150 assembly operations and can cost as much as £20,000.

General Principles



The anode target disc (1) rotates on a highly specialised ball bearing system (2). The target is subjected to a focused stream of electrons (3) emanating from the cathode (4) and accelerated by a high potential difference between the target disc and the cathode, when the electron beam hits the anode it produces the x-ray beam (5).

The Cathode



The cathode of the rotating anode x-ray tube provides a controlled source of electrons for the generation of the x-ray beam.

The electrons are produced by heating a tungsten spiral wire or filament, the temperature of which controls the quantity of electrons released. This determines the tube current (mA) and thus becomes the control means for selecting mA. At high temperatures the tungsten starts to vaporise.

The filament is supported in and one end connected to a highly polished nickel focussing cup which along with carefully designed shape provides electrostatic focussing of the electron beam onto the anode.

The Filament

The filament is an accurately constructed tungsten wire coil of precise pitch and length, it is crystallised during construction by heating to a high temperature in the absence of oxygen, this crystallised structure gives the filament dimensional stability expanding and contracting only a minute amount during the heating cycle from 25⁰C to 2600⁰C.

The dimensions of the wire and its site in the focussing cup determine the large and small foci of the tube.

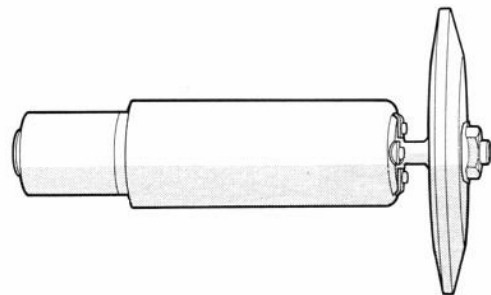
The Rotor and Bearing System

The anode disc needs to be rotated at high speed and this is achieved by attaching the stem to a large copper rotor, which forms the armature of a motor.

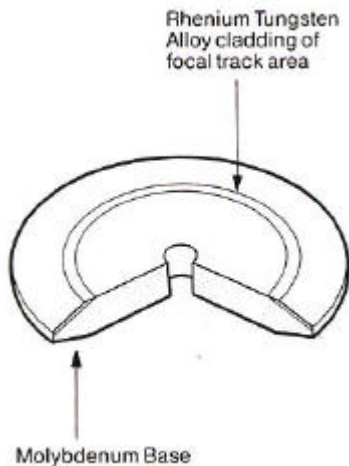
The target disc, or rotor, is mounted on a shaft extending from a rotor body, which can spin on internal bearings on the rotor shaft.

This rotor shaft extends through the end of the insert to the outside of the insert vacuum for connection to the anode wire, and also is the mounting point for the insert inside the housing.

The rotor bearings are special as they need to operate in a vacuum, conduct a high voltage and reach high temperatures (500⁰C). Using steel bearings lubricated by silver powder solves the problem.



The Anode



The anode disc is between 55mm and 100mm in diameter and 7 mm thick machined to high tolerance to prevent in balance and wobble.

The disc will experience rotational speeds up to 10,000 RPM and temperatures of 2000°C

The disc has a tungsten rhenium target area as tungsten has a high melting point 3370 °C and atomic number of 74. The addition of a small quantity (5-10%) of rhenium prevents crazing of the anode surface, the tungsten is faced onto a molybdenum disc as molybdenum whilst not having as high a melting point as tungsten has twice the heat capacity.

The target disc is mounted on a molybdenum stem attached to the copper rotor.

The target is cooled by radiation to the glass then oil.

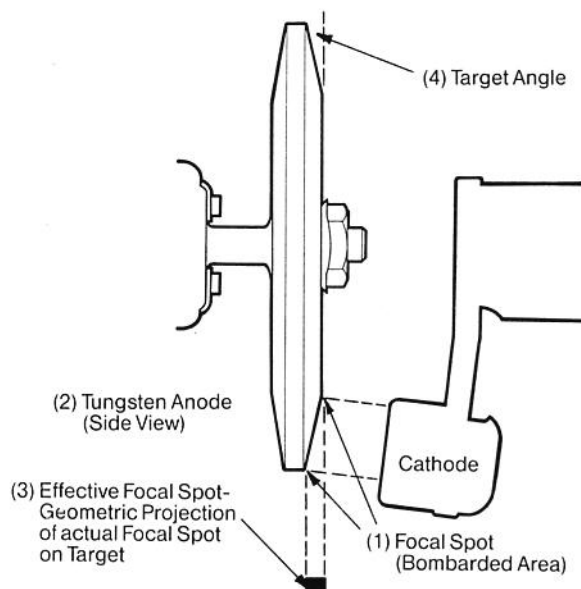
Focal Spot size.

The area of the track bombarded by electrons determines the tube loading, if the area bombarded is small and a high loading is applied the track would melt.

The effective focal spot size is how the focal spot appears if viewed along the axis of the central ray, the true size is the size if viewed from the filament.

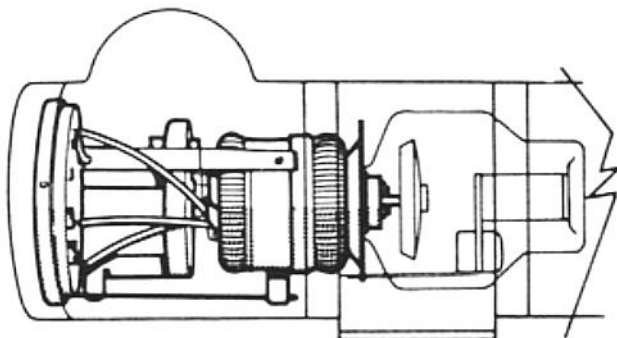
The anode angle is measured from vertical to the angle of the anode and is about 15 degrees,

A smaller angle would make a smaller apparent focal spot. However beam coverage would be limited by the absorption of x-rays by the anode, the anode heel effect.



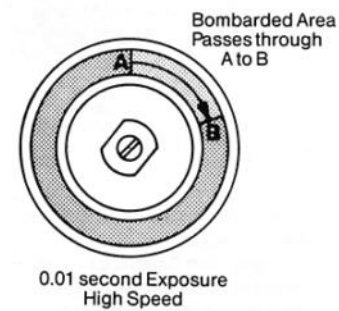
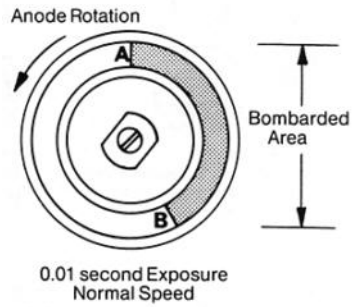
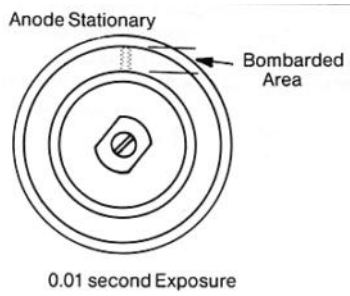
The Anode Stator Motor

The anode stator motor must accelerate the anode to working speed rapidly ready for an xray exposure then must bring it back to stationary equally rapidly to prevent wear and wobble on slowing down.



The “motor” consists of electromagnet coils round the glass to provide a rotating magnetic field to induce the currents and produce the forces needed to rotate the copper rotor

Anode Rotation



The diagram on the left demonstrates the area of the anode disc bombarded hence heated by the filament electrons during an exposure of one hundredth of a second for different anode rotation speeds.

1) No rotation all the heat hits the same point

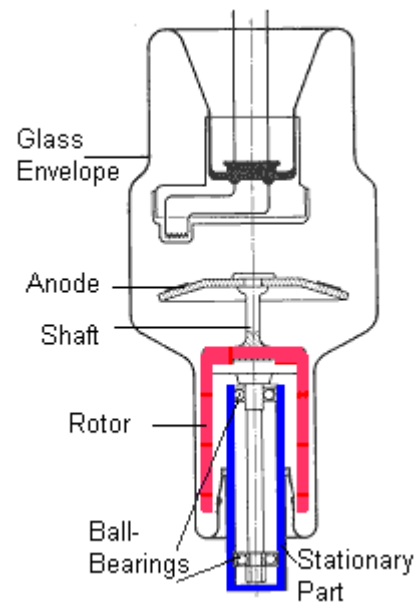
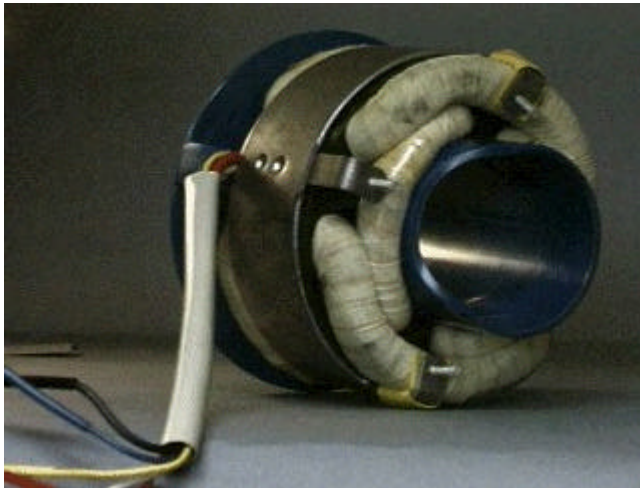
2) Anode speed of 6000 RPM almost half the track area is heated

3) Anode speed of 10,000 RPM all the track area is heated with some overlap.

The Anode Stator Motor

An external electromagnetic field, produced by a winding (stator) outside the glass envelope, drives the rotor. Both together work as an asynchronous motor.

The air gap between rotor and stator isolates both from each other, since the winding is electrically close to ground and the anode lays on high potential during operation. On the other hand the gap reduces the efficiency of the motor significantly.



Due to this distance, the power supply for the motor must be relatively high, in order to speed up the anode in an acceptable short time.

An optimal rotation is achieved when a body rotates without creating axial forces. To reach those condition, a "balancing" takes place during the tube manufacturing process. This means, material is added to or removed from the anode and the rotor, till the centre of gravity almost coincides with the artificial axis of rotation.

Only then, do no vibrations occur.

Practically, this is never achievable during operation.

The Rotor consists of a copper cylinder and rests in ball bearings for smooth movement.

The bearings cannot be lubricated with ordinary grease because it would affect the vacuum and, as a consequence, the high tension characteristics of the tube.

Soft metals such as lead and silver are applied to separate the ball bearings and the running surfaces, in order to prevent the possibility of "jamming" in the vacuum.

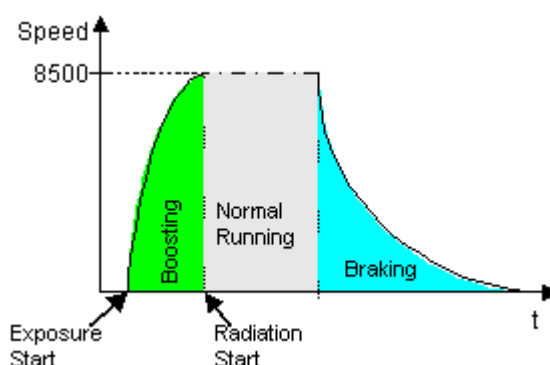
This form of lubrication limits the life time of the bearings in the x-ray tube to about 1000 hours.

Therefore, the running time needs to be as short as possible, which does not allow continuous rotation.

The rotation is controlled when a radiography is started.

The control works so, that the anode only rotates when radiation is required and is braked immediately afterwards.

The high inertia of the heavy metal disc leads to some delay in getting the rotor up to speed. This "Boosting" takes up to 2,5 sec, depending on the type of starting



device and anode. Radiation can only be started in the grey area zone after the anode reached its final speed. The thermic loading of the anode should not heat up the ball bearings too much. Here, the thin shaft serves as a barrier for heat transport. The bearings conduct as well the tube current, flowing between the stationary part of the motor (positive high tension) and the anode.

The stator consists of several windings which are equally spread out around the neck of the tube. They induce a rotating electro-magnetic field which interacts with the rotor, causing it to rotate synchronously.

The simplest power supply is a 220 V AC source. It was used in old generators for the normal speed anode.

A capacitor C provides the stator with a second phase.

The current in the two phases I and II have a phase shift of 120° to each other, which produces the rotating field.

The value of the capacitor depends on the type of stator coil.

This stator is called "two-phase stator".

A two-phase stator can drive the anode with different speeds depending on the formula

$$n_{\max} = 60 \times \text{frequ. line}$$

The "normal running tube" with a 50 Hz line consequently rotates with 3000 rpm.

But, because of the large air gap between stator and rotor and the short acceleration time, there is a slip of about 6%.

Thus, the anode runs only on 2800 rpm.

For higher speed ("rapid tube"), the frequency of the power supply is changed to 150 Hz. This results in 8500 rpm.

There is a 20% increase of speed with a 60 Hz line frequency

The latest innovation is a three phase stator for rapid speed, which does not need the phase shift capacitor anymore and has a better efficiency.

It reduces the acceleration time for the anode to the half and was used with the Megalix tube for the first time.

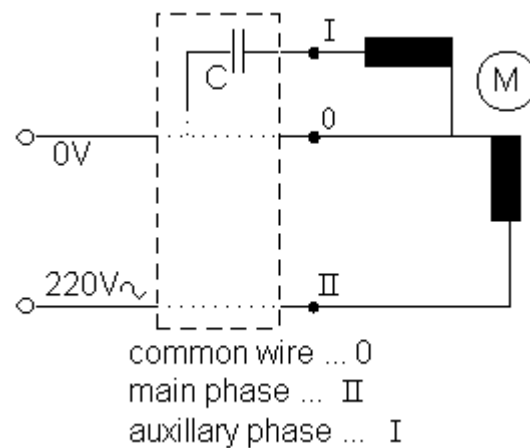
This image shows the terminals at the anode side of the tube housing to connect the stator supply.

A special stator cable has to be connected here according to the proper technical documentation.

The starting device supplies the motor, controls and monitors the rotation.

The rapid rotation formerly required a special power supply to produce 150 Hz with high power to run the anode at 8500 rpm.

Today, a DC-AC converter supplies the power, controlled by a microcontroller MC. This device is able to produce every common frequency with two or three phases.



Depending on the type of generator, the anode starting device alternatively supplies up to four different tubes.

All necessary tube data are nowadays stored in an EEPROM .

The microcontroller MC switches and controls the starting device according to the tube type selected.

This includes

- the acceleration time (boosting)
- normal running (to overcome friction)
- anode braking
- fluoroscopy rotation
- monitoring

With the exposure start signal, the anode is accelerated with high power to reach the final speed in an acceptable time. The counter CTR starts counting the time when the current in phase II reaches a certain value. If the current is too low we can assume, that the nominal speed was not reached, what requires to block the radiation start.

After about one second the counter delivers the ROT signal which enables the MC to start radiation. In the same time, the power for the motor is reduced just to keep the anode running. This lowers the noise and heat production of the stator.

After the exposure is finished and the switch released again, the DC-AC converter is switched to supply a DC voltage to the stator. This induces an eddy-current in the rotor which brakes the anode to a standstill in order to save the ball bearings.

Most anodes, especially the stress relieved one, rotate as well during fluoroscopy. This is achieved with low power and about 20 Hz.

Why must the rotation be monitored and the exposure blocked when the anode does not run with the correct speed?

The advantage of a rotating anode is the increased load which can be applied to the focal spot (see subchapter "The Anode"). If this load is fed to a *not moving* anode the surface would melt and destroyed. The consequence is, material evaporates which ruins the tube vacuum.

A direct measurement of the revolution is not necessary since the correct speed is reached when the supply and rotor work properly.

With a mechanical defect of the ball bearings the tube has to be replaced anyway.

HOW TO MAXIMIZE X-RAY TUBE LIFE

Minimise filament boost (“prep”) time

Boost time will usually exceed the actual exposure time. High filament current applied for too long will shorten filament life and will lead to unstable operation as evaporated tungsten from the filament is deposited onto the glass envelope. This is especially the case at high mA stations.

Use lower tube current (mA)

The high filament current required to produce high tube current (mA) will shorten filament life and will lead to unstable operation as evaporated tungsten from the filament is deposited on to the glass envelope. Whenever possible, use a lower mA station and a longer exposure time to arrive at the desired mAs.

Follow rating charts and anode heating/cooling curves

Operation beyond published ratings will result in premature focal track wear or damage. Even moderate etching of the focal track will result in a fall-off in radiation output, because electrons from the filament which strike in micro-crevices in the target material produce radiation that is mostly absorbed in the surrounding target material. More severe etching, or melting, results in the liberation of gasses from the target material, which causes tube instability. Excessive heat transfer from the target into the rotor body will cause bearing failure or slow rotation which will result in melts on the focal track.

Limit operation to 80% of maximum single exposure ratings

although higher power levels are both possible and permitted, this reduction will help assure long focal track life. Also, it will minimise the reduction in radiation output associated with a roughened focal track.

Do not exceed anode thermal capacity or dissipation rate of the target

the greatest danger is to heat flow into the bearing structure, as discussed above. In addition, gasses may be emitted from the various metals within the tube if the temperature reached during clinical use is appreciably higher than that used during the “outgassing” stage of manufacture. If outgassing occurs during clinical use, the tube will become unstable. (“Aging” the tube may reverse the process but this is not assured.)

Do not make high mA exposures on a cold target

Uneven expansion caused by thermal stress from a high power exposure can result in a cracked target. Do not assume that a “thermally relieved” target design provides absolute protection. Always follow the recommended warm-up procedure. The procedure may need to be repeated between patients, if the “idle” time is long enough, in addition to being performed at the beginning of the workday.

Avoid long intervals between spot-films

Most systems provide for a “holdover” period of up to approximately 25 seconds between spot-films, during which the rotor is kept at high speed before the rotor brake/reboost cycle is allowed to occur. In some systems, the filament current remains at the exposure value during this period, thereby causing evaporation of filament material and resultant tube instability.

Limit rotor start/stop operations

Rotor start/stop operations especially to/from high speed (150/180 Hz) generate considerable heat in the stator windings, which will lead to stator damage in extreme cases. Generally there should be a minimum of 30 to 40 seconds between starts.

Tubes equipped with a heat exchanger will be less sensitive to this potential problem because oil circulation will help prevent hot spots from occurring around the stator windings.

<http://www.inmarkcorp.com/xray/tips.html>