Machlett X-Ray Tubes (Great Britain) Ltd
P.O. Box No. 2 East Lane, Wembley, Middlesex, England, HA9 7PR
Telephone: 01-904 5263 Telex: 922177
Cables: Machlett Wembley

a member of the GEC Medical Equipment Group of Companies

Printed in England by Albert Frost & Sons, Rugby

MACHLETT x-ray tubes

MACHLETT

Since its original introduction in 1939, the Machlett Dynamax Rotating anode X-ray tube has undergone many changes in detail, but the latest tubes maintain the long tradition of dependable X-ray sources.

Some comparisons between then and now.

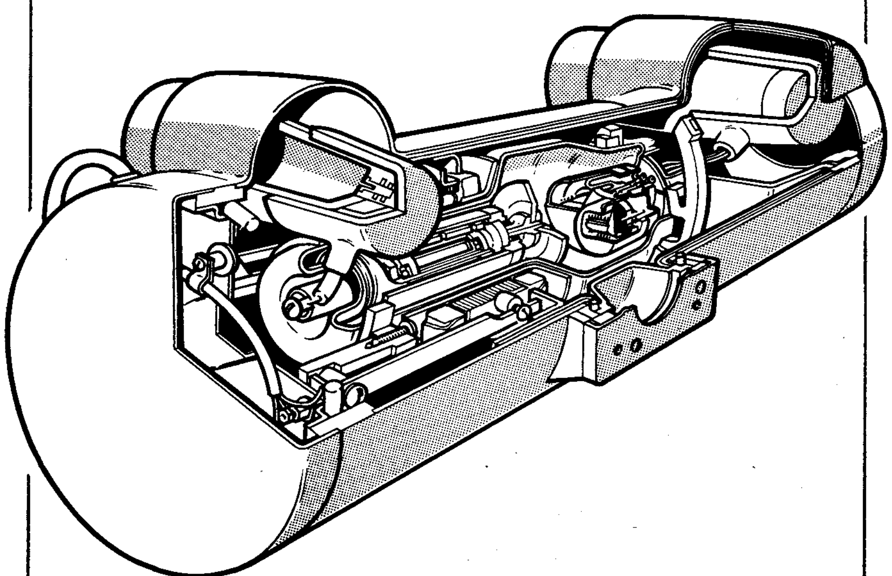
Radiographic ratings have increased from 40kW to over 100kW

Anode thermal storage capacities have increased from 72,000HU to 400,000HU.

Anode rotational speeds from 3000rpm to over 10,000rpm.

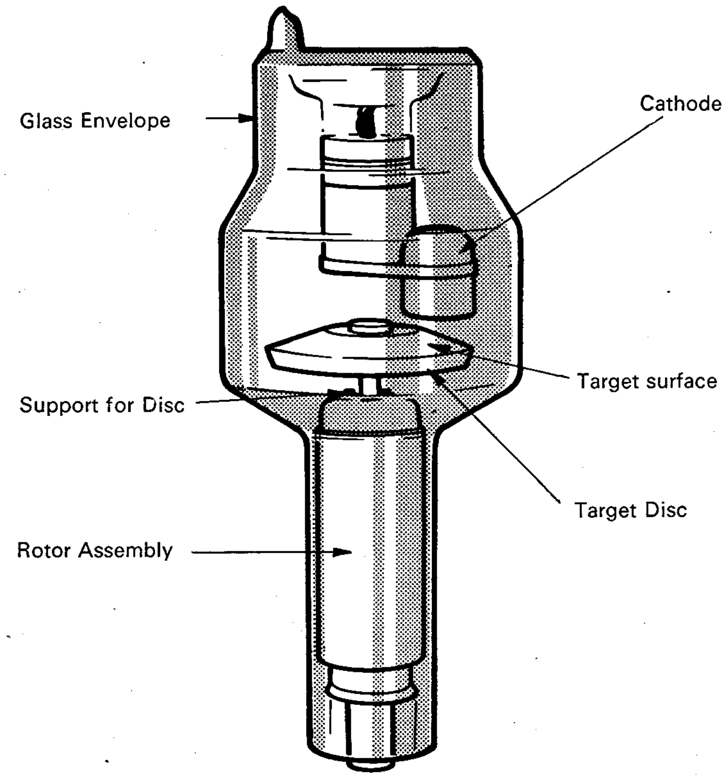
Maximum voltage ratings from 90kVp to 150kVp.

In this booklet you will discover how this high level of performance is possible and how each major component – cathode, anode, rotor, tube shield etc. – contributes to the final result.

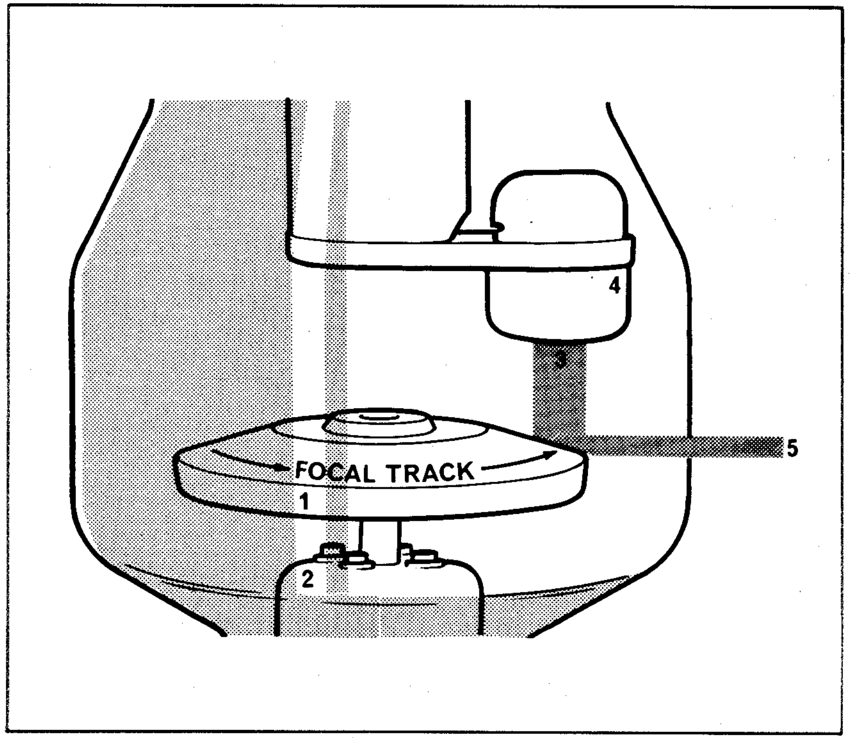


An inside view of 372 parts ....
144 assembly operations .... with over
400 different individual tests and
inspections that go into the
Machlett Rotating Anode X-ray Tubes

The X-ray insert tube



General principles



In the Dynamax Rotating Anode X-ray Tube

a disc target (1) rotates on (2) a highly specialized ball-bearing system. This target is subjected to a focused stream of electrons (3) emanating from the cathode (4) and accelerated by a high-voltage potential between the electrodes.
The electron beam strikes the target at an angle which permits maximum loading while maintaining a small focal spot. When the electron beam strikes the target it produces the useful x-ray beam (5).
Very little of the electron beam energy reaching the target is converted into x-rays, the bulk of the energy heats the target. The heating intensity may be thought of as the effect of 100 electric fires or a 50 hp motor concentrated onto an area 1·5 × 7·5mm.
It is the precise control of this great intensity which makes the Machlett rotating anode x-ray tube the practical and widely used device that it is.

The Cathode

The cathode of the rotating anode x-ray tube provides a controlled source of electrons for the generation of the useful x-ray beam. The electrons are produced by heating a tungsten spiral wire – or filament – to a predetermined temperature. (It is the temperature which controls the quantity of released electrons). The number of electrons produced determines the x-ray tube current and thus becomes the control means for selecting milliamperage. The temperatures required for electron production cause tungsten evaporation from the filament. At high mA levels this evaporation takes place rapidly, while at standby it is reduced almost to the vanishing point.

Electron Source: The Cathode Head

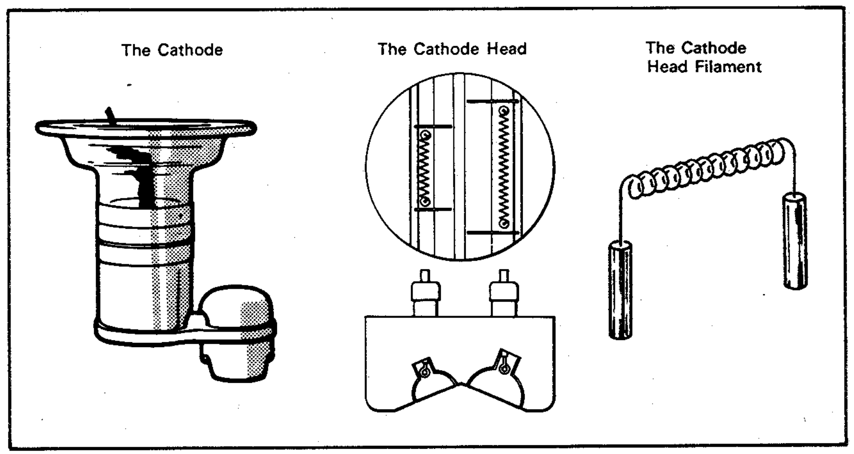
Thermally cleaned, machined nickel forms the basic 'lens' for an electron optical system......
A tungsten helix filament provides electrons.

Cathode Head

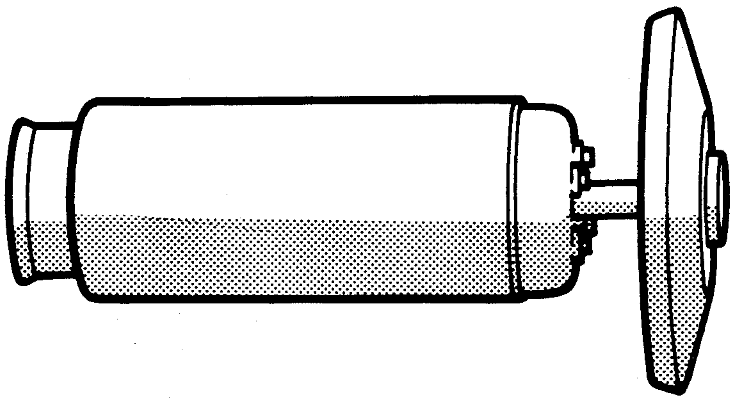
Machined of pure nickel, the cathode is cleaned in a hydrogen furnace and stored in oxygen-free pressurized cabinets prior to use. The rounded slotted grooves in which the filament wires are mounted form a critical lens which, together with nickel tabs, forms an electrostatic focusing system to shape the electron beam. The high load-carrying capacity of the tube and the accurate focal spot size result from the accuracy of the machined grooves, the placement of the focusing tabs, and the location of the filament within the grooves.

The Cathode Head Filament

Sintered, drawn to the precise required diameter, the tungsten filament wire is wound in a coil of precise pitch and length. It is then heated (in a protective atmosphere to prevent oxygen contamination) by a high current. This recrystallizes the metal and provides maximum dimensional stability over a lifetime of temperature 'cycling' from room temperature to about 2600°C. Wire coil dimensions, along with other factors, determine 'large' or 'small' focal spots.



The anode



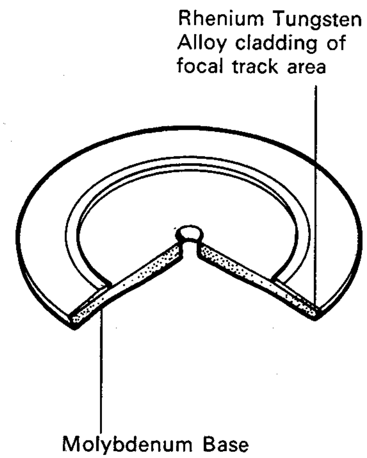
X-ray Source: The Anode

The anode of the rotating anode x-ray tube provides the means of converting the incident electron energy into x-ray and thermal energy. It also provides a means of dissipating the thermal energy. The anode is formed of a massive target disc (usually of tungsten) mounted on a thin molybdenum stem which in turn is supported from the copper rotor which forms the armature of an electric motor and is mounted on ball bearings.

A High Vacuum Ball Bearing System

Unusually stringent requirements are made on Machlett ball bearing rotational systems: since Machlett ball bearings must operate in a vacuum, a lubrication method is required which does not impair this vacuum. Conventional lubricants vaporize under vacuum conditions and therefore are unacceptable. Also, since the bearings must operate through a temperature range from just above freezing to 500°C, special metals and treatments are required. Heat resistant steels with metal film lubricants deposited on the steel balls provide the required long life structure.

The target disc

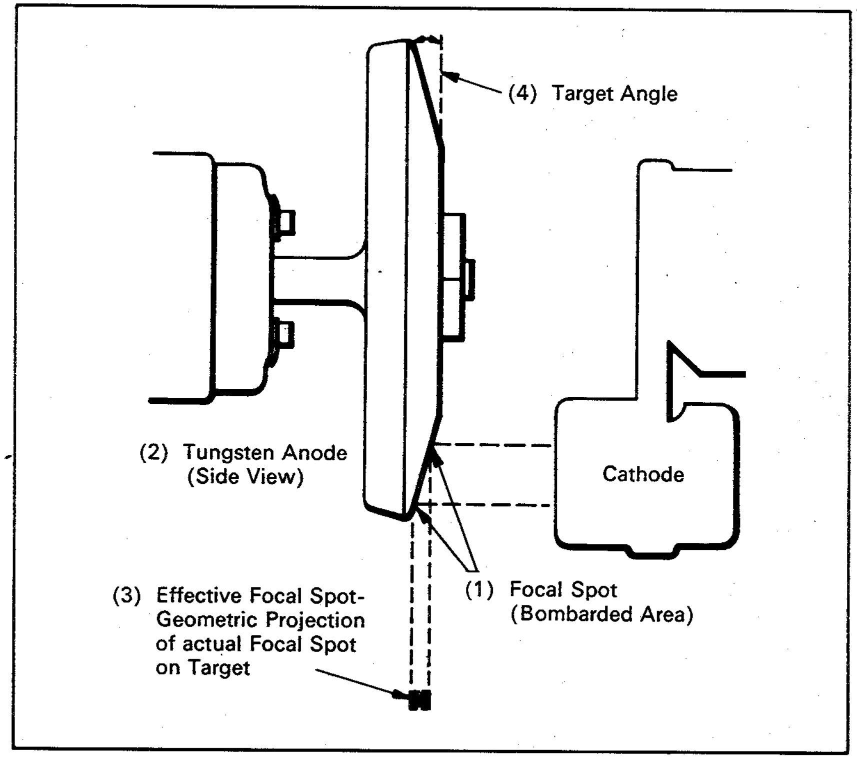


The Disc Anode

Is a massive disc that absorbs tremendous energy loads. It sustains temperatures well above 1000°C (with focal spot temperatures well above 2000°C); it rotates 100,000,000 times or more during a lifetime of x-ray production.
The material of the target disc must have (a) a high melting point and (b) a high atomic number because the efficiency of x-ray production increases with atomic number.
Tungsten – melting point 3370°C atomic number 74 – is the element of choice and is the basic target material of most x-ray tubes.
Molybdenum – melting point 2620°C atomic number 42 – has a specific heat twice that of tungsten. By facing a disc of molybdenum with tungsten, the thermal capacity of a target of a given weight can be increased. Replacing the pure tungsten with an alloy of tungsten (90-95%) and rhenium (5-10%) – melting point 3170°C atomic number 75 – produces a target with greatly improved resistance to focal track erosion during use.

The most popular target diameters are 55mm, 70mm and 100mm. Pure molybdenum targets are recommended for soft tissue radiography, e.g. mammography where the molybdenum characteristic radiation produces radiographs with greater contrast than obtained with the continuous x-ray spectrum from normal tubes.
The target disc is cooled by radiation. It is supported on a thin molybdenum stem to reduce heat input to the rotor. The rate of cooling of the disc is proportional to the fourth power of the target temperature.
By special treatment of the target surface the emissivity can be increased, thereby increasing the cooling rate.

MACHLETT



The size of the bombarded area

On the target (1) determines the amount of permissible energy or loading the tube can accept. The size of the effective or *projected* spot (3) which is related both to the size of the bombarded area and the bevel of the anode or target angle (4) helps determine the x-ray image sharpness.

The size of the bombarded area increases as the target angle is reduced.

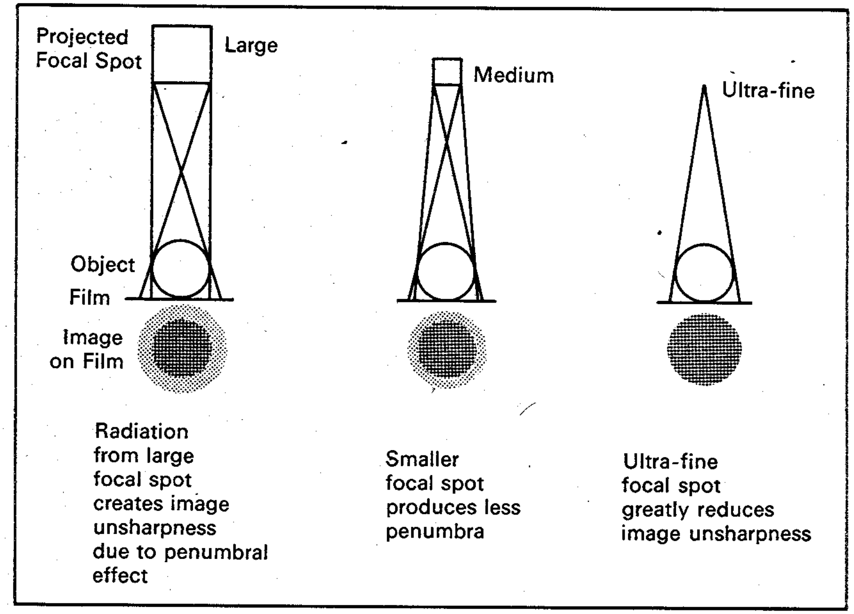
The bombarded area =

$$\frac{\text{the projected area}}{\text{sine target angle.}}$$

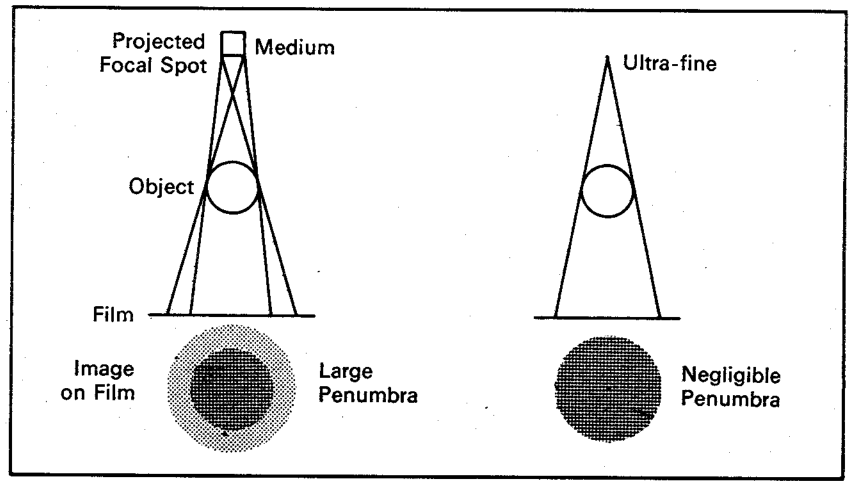
A target angle of 15° is widely used but Dynamax tubes are available with other target angles. However smaller target angles reduce the film size covered at a given distance.

Target angle	7°	10°	12°	15°	20°
Distance	150	100	83	67	50

Distances in centimetres to cover a 36·5 × 36·5 cms film



As the focal spot gets smaller, the image detail improves (all other factors being kept the same). This is because the shadow edge (or penumbra) around the image decreases. Note that these diagrams exaggerate the focal spot/object size relation.



Enlargement techniques require use of the 'ultra-fine' focal spots because the greater object-film distance increases the penumbral effect. It should also be noted that increased separation between object and film greatly decreases the effect of scattered radiation.
Dynamax tubes are available with focal spots from 0·3mm to 2·0mm. Some 0·3mm spots can be electrically biased to produce even finer foci.

MACHLETT

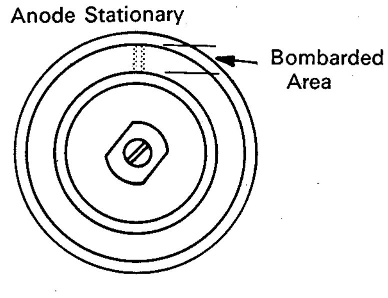
Anode rotation

High Speed Rotation allows greater Focal Spot Loading

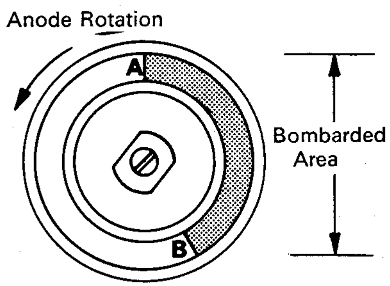
Fundamental to the performance of any Machlett tube is proper anode rotation. Rotation is achieved through an electric motor, the stationary part of which (field coils) is external to the glass x-ray tube, and the rotary part of which (armature) is an integral part of the anode bearing support structure. Increased ratings are possible as anode rotational speed is increased. Practical speeds up to 10,000 rpm are widely used today.

Anode Rotation vs Instantaneous Loadings

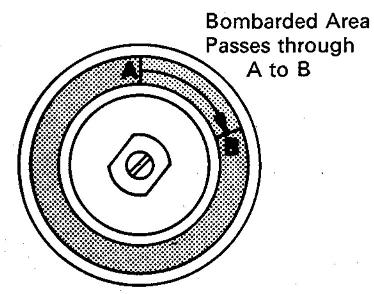
The shaded portions, in the accompanying diagrams show the bombarded target area for a short time exposure on a Machlett anode. The faster the rotation, the greater the surface (or bombarded area) exposed to the electron beam. The larger the area over which the energy is distributed, the higher the permissible instantaneous loadings. However, as exposure times increase, so does the exposure 'overlay' with a consequent reduction of heat absorbing efficiency.
High speed rotation (10,000rpm) allows significant rating increases for short time loadings; these improved ratings also apply to serial exposure work such as cinefluorography and angiography.
Alternatively smaller focal spot sizes can be used with a given rating to improve definition.



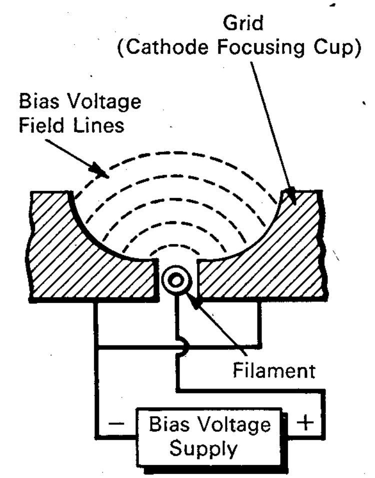
0·01 Second Exposure



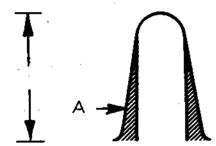
0·01 Second Exposure
Normal Speed



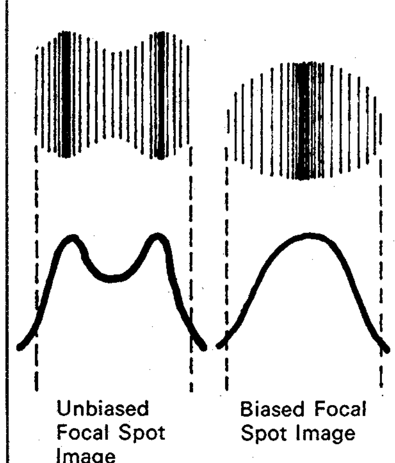
0·01 Second Exposure
High Speed



X-ray producing Waveform



A part of waveform removed by grid pulsing



Grid Control of Cathode for Ultra-Rapid Exposure

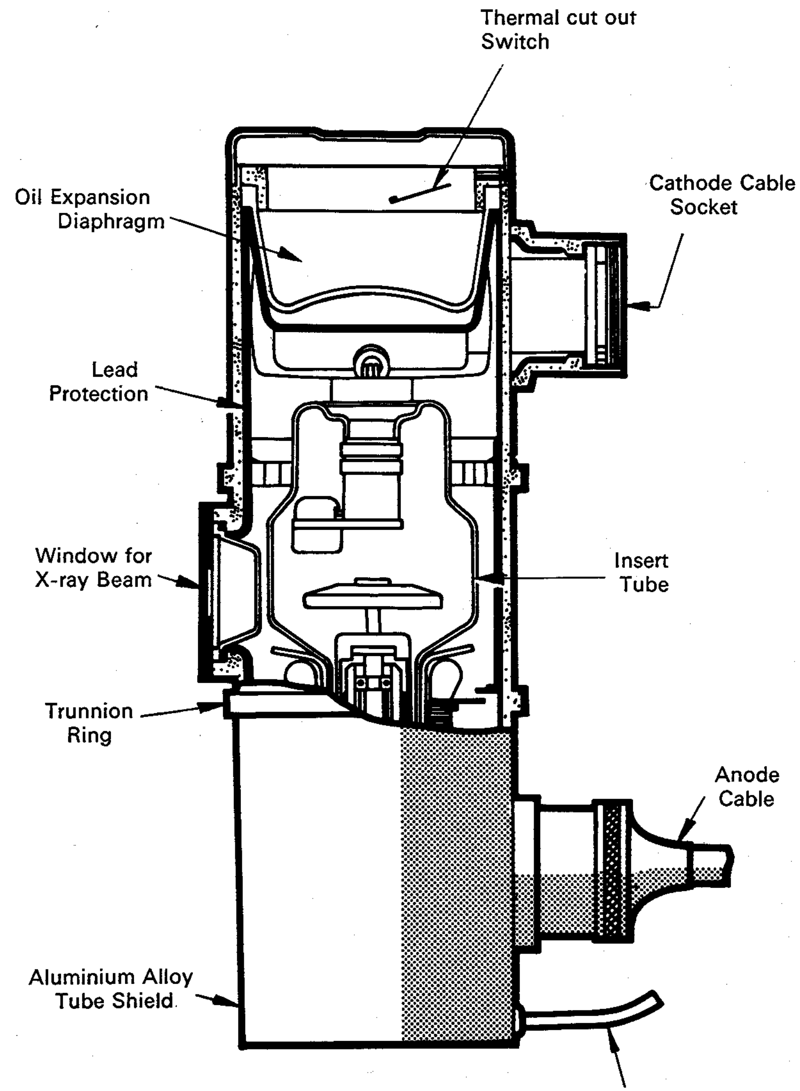
By electronically controlling the cathode emission in an 'on' or 'off' system, a simple and reliable means of controlling the x-ray beam has been achieved. Using the cathode focusing cup as a 'grid' (analogous to the grid in a triode), an electrostatic field may be created which will overcome anode attraction for the cathode electrons and cause them to return to form a 'cloud' around the cathode. Changing the polarity of the grid field 'releases' the electrons which are instantly attracted to the anode. In this manner x-ray exposure rates of 1/1000th of a second or less are achieved. At these rapid rates, image blurring is, of course, virtually eliminated. When used with a single phase supply the x-ray beam is comprised of a more nearly uniform energy spectrum since the grid action shaves off the lower voltage portions of the wave-form producing the x-ray beam.

Grid Biasing of Cathode for Ultra-fine Focus

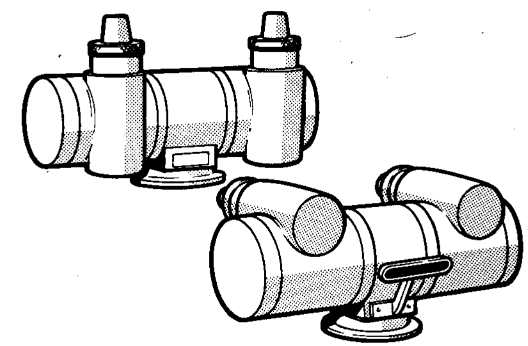
Application of a negative bias voltage insufficient to produce cut off reduces the focal spot size and also improves the resolving capability by changing the energy distribution within the focal spot.

MACHLETT

The X-ray tube assembly



The x-ray insert tube is mounted in a x-ray tube housing to produce a x-ray tube assembly.



The x-ray tube housing

Allows precise mounting of the x-ray tube 'insert'.
Contains the anode rotation power source (the stator).
Provides high voltage terminals.
Insulates high voltage.
Shields x-radiation.
Provides the x-ray tube 'window'.
Provides means for its mounting on the tube stand.
Provides a reference and attaching surface for x-ray beam collimating devices.

X-ray Shielding

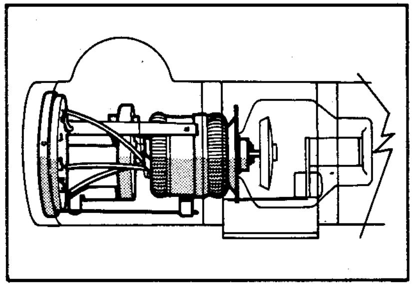
The x-ray tube housing is lined with lead to reduce the leakage of x-rays outside the useful beam to a low level (less than 100mR at 1 metre in 1 hour). The useful beam emerges from the shield at an opening in the tube shield at the x-ray port. The port is an inverted plastic cup – which, together with the oil between the port and the x-ray tube and the glass wall of the tube, provides a filter for the soft x-rays equivalent to approximately 0·7mm of aluminium.

Oil Filling

The x-ray tube housing is filled with specially processed oil to provide high voltage insulation and to conduct heat from the x-ray insert tube to the walls of the tube shield. Since oil expands when heated, an oil expansion diaphragm of oil resistant synthetic rubber is provided. The movement of this diaphragm can be arranged to operate a pair of electrical contacts when the housing reaches its maximum safe temperature.

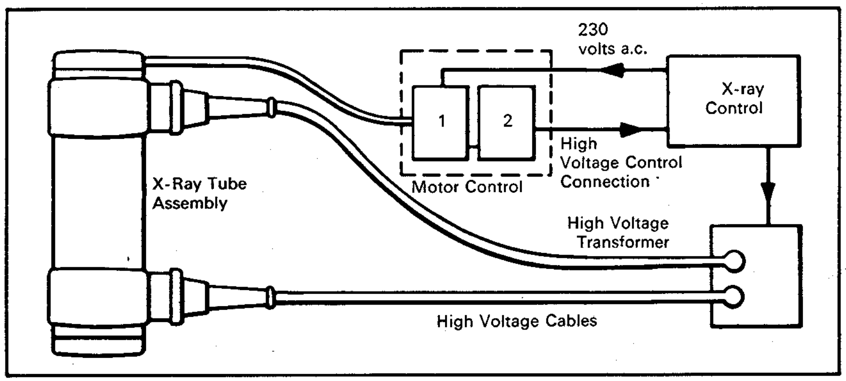
MACHLETT

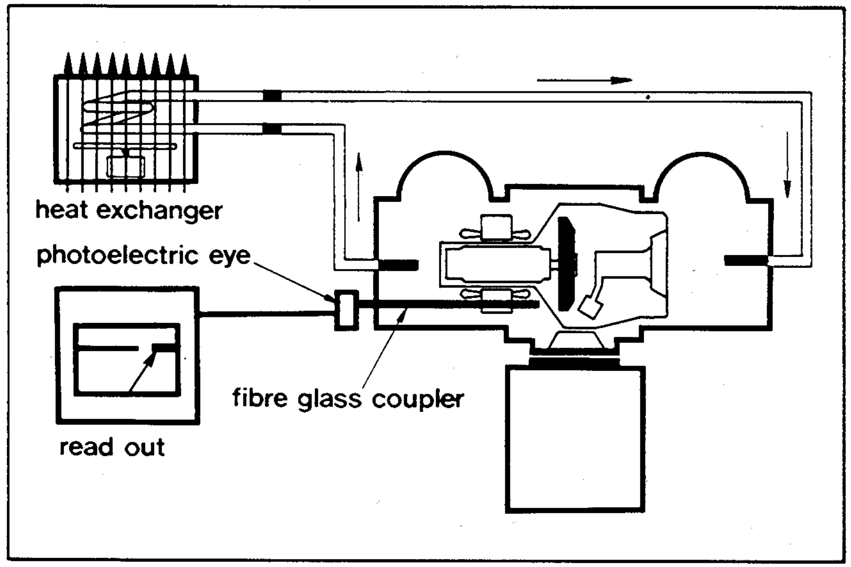
The motor control



The x-ray tube 'insert' requires an a.c. power source to rotate the anode. This power is provided by an external device (called the motor control unit) connected to the stator windings in the housing which are similar to familiar electric motor windings. The stator may also be powered by a d.c. source (from an additional control device) to stop or to brake the rotor. The requirements for a motor control unit are:
The rotor must be started and accelerated to running speed.
After attaining running speed the stator power should be reduced in order to maintain a safe heat input to the stator windings.
The x-ray tube filament must be maintained at a low standby level (to provide satisfactory filament life) and boosted to the proper temperature for exposure.
High voltage must be withheld from the tube until the rotor (target) reaches running speed and the filament is boosted to the correct temperature.
Provisions must be made to sense stator power failure and/or wiring or connection errors and to prevent application of high-voltage to the tube and so prevent tube damage.
Provision should be made for continuous anode rotation during fluoroscopy when using fractional millimetre focal spot tubes.
Where high speed anode rotation (approximately 3 × normal speed) is employed, a suitable braking device must be added to slow the rotor rapidly to normal speed.

The basic system: Section 1 provides power to the stator and is interconnected with Section 2 which permits application of high voltage to the tube only after all necessary operating conditions have been satisfied.





X-ray tube housing cooling is normally by air convection. A small fan or air circulator fitted to the housing will increase the air flow over the surfaces and can thereby double the cooling rate. Even this will not match the cooling rate of the latest heavy duty anodes. Circulating the insulating oil through an external heat exchanger results in a cooling rate many times greater than that for the basic tube housing. The oil flow around the insert tube improves the insulation and avoids the formation of local hot spots.

The anode heat content can be checked by means of an infra red sensor which looks at the anode through an optical window in the housing. An electronic readout shows how hot the anode is—what further work can be done and when to stop.