5.3.3.3. Stationary and rotating anodes

For X ray examinations that require only a low anode current or infrequent low power exposures (e.g. dental units, portable X ray units and portable fluoroscopy systems), an X ray tube with a stationary anode is applicable (Fig. 5.9). Here, a small tungsten block serving as the target is brazed to a copper block to dissipate the heat efficiently to the surrounding cooling medium. As the focal spot is stationary, the maximum loading is determined by the anode temperature and temperature gradients.

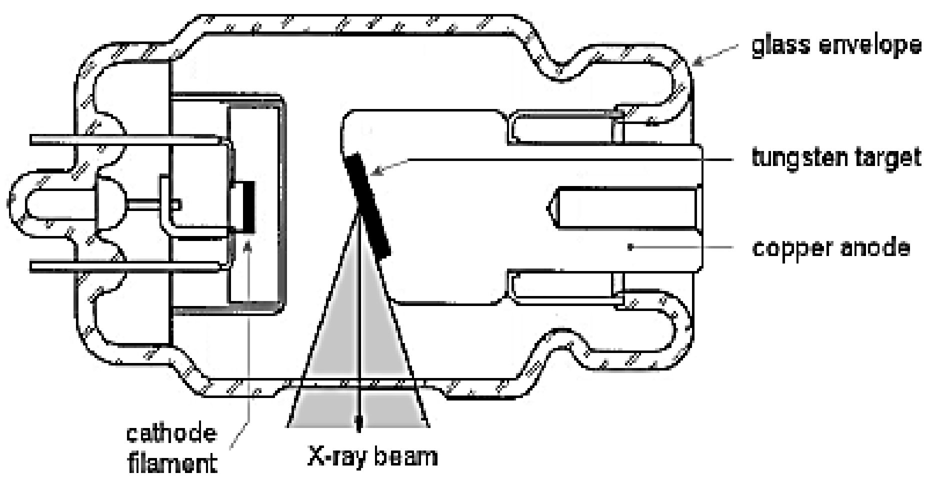

FIG. 5.9. Dental X ray tube with a stationary anode.

Most X ray examinations need photon fluences that cannot be obtained with stationary anodes, as bombarding the same spot with higher anode currents leads to melting and destruction of the anode. In a tube with a rotating anode, a tungsten disc rotates during an exposure, thus effectively increasing the area bombarded by the electrons to the circumference of a focal track. The energy is dissipated to a much larger volume as it is spread over the anode disc (Fig. 5.10). The anode disc is fixed to a rotor and a spindle with a short stem. The spindle is supported by two ball bearings. In newer developments, floating bearings with liquid metal have been introduced.

The rotating anode is attached to the rotor of an asynchronous induction motor. The rotor is mounted within the tube housing on bearings (typically ball bearings). The squirrel cage rotor is made up of bars of solid copper that span the length of the rotor. At both ends of the rotor, the copper bars are connected through rings. The driving magnetic fields are produced by stator windings outside the tube envelope. The rotational speed of the anode is determined by the frequency of the power supply and the number of active windings in the stator. The speed can be varied between high (9000–10 000 rev./min) and low (3000–3600 rev./min) values using all three or one phase only. In examinations requiring rather low anode currents, as in fluoroscopic applications, the tube is run at low speed. Rotor bearings are critical components of a rotating anode tube and, along with the whole assembly, cycling over a large temperature range results in high thermal stresses.

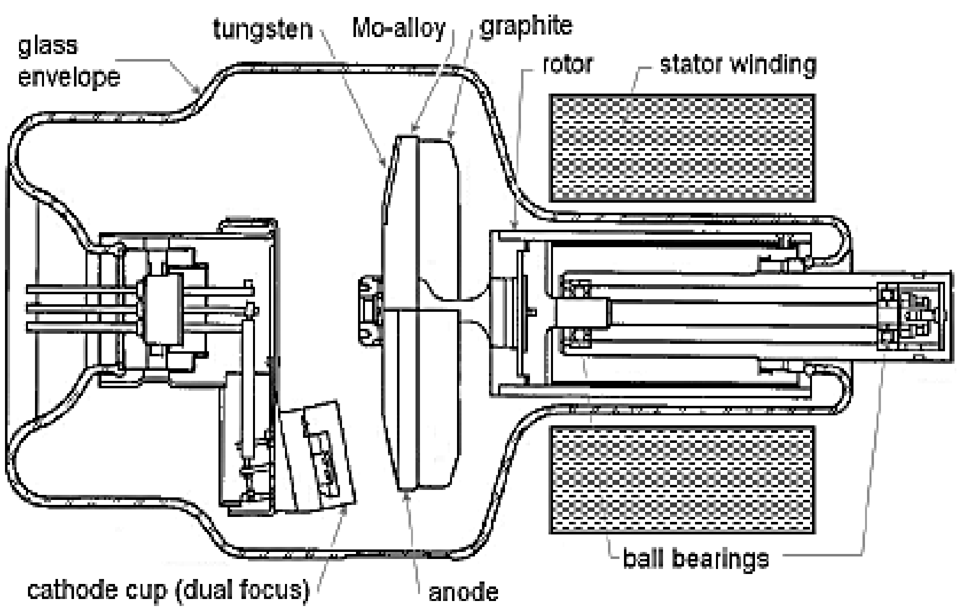

FIG. 5.10. Xray tube with a rotating compound anode and a glass envelope. Mo: molybdenum.

5.3.3.5. Tube envelope

The tube envelope maintains the required vacuum in the X ray tube. A failing vacuum, resulting from leakage or degassing of the materials, causes increased ionization of the gas molecules, which slows down the electrons. Further, a current of positive ions flowing back could impair or destroy the cathode filament. The envelope is commonly made of glass but high performance tubes increasingly have glass–metal or ceramic–metal envelopes.

The X ray beam exits the tube through a window in the envelope. To reduce absorption, the thickness of the glass is reduced in this area. If low energy X rays are used, as in mammography, the exit port is a beryllium window, which has less absorption than glass because of its low atomic number.

5.3.3.6. Tube housing

The X ray tube (often referred to as the insert) is installed in a tube housing that provides the structural support required (Fig. 5.12). The space between the housing and the envelope is filled with transformer oil, serving as electrical insulation and for heat removal from the envelope surface, which is heated by the infrared radiation from the anode. The change of oil volume with varying temperature is taken care of by the expansion bellows. The oil carries the heat away to the housing by convection, sometimes enhanced by forced cooling with a ventilator or heat exchangers.

The housing also provides radiation shielding to prevent any radiation except the primary beam from leaving the housing. The inside of the housing is lined with lead sheets to minimize leakage radiation. The maximum acceptable exposure due to leakage radiation is limited by regulation. Further, tube housings provide mechanical protection against the impact of envelope failure.

5.4. ENERGIZING AND CONTROLLING THE X RAY TUBE

The X ray generator provides all the electrical power sources and signals required for the operation of the X ray tube, and controls the operational conditions of X ray production and the operating sequence of exposure during an examination. The essential components are a filament heating circuit to determine anode current, a high voltage supply, a motor drive circuit for the stator windings required for a rotating anode tube, an exposure control providing the image receptor dose required, and an operational control (Fig. 5.13). The operational control is often accomplished by a microprocessor system but electromechanical devices are still in use. Modern generators provide control of the anode temperature by monitoring the power applied to the tube and calculating the cooling times required according to the tube rating charts

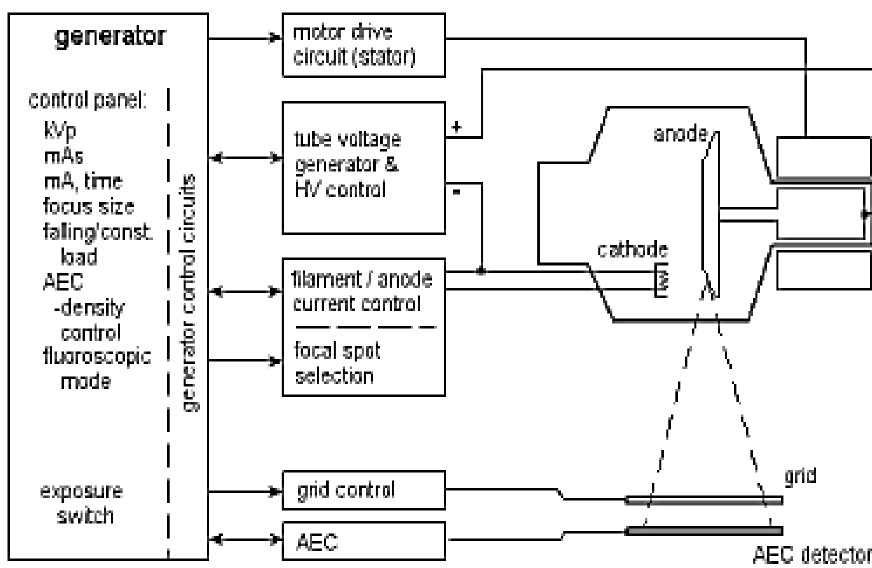

FIG. 5.13. Schematic diagram of a basic X ray generator. AEC: automatic exposure control; kVp: peak voltage.

An isolated transformer supplies the filament heating current. The generator is programmed to set the heating current according to the tube characteristics. Heating currents range up to 10 A with voltages of <15 V AC (alternating current). To minimize thermal stress and increase durability, the filament is permanently preheated to a temperature at which thermionic emission is negligible.

The thermal inertia of the filament limits the speed of change in the tube current (e.g. falling load). The thermal time constants range from 50 to 200 ms. For a frequency of heating currents of 100 or 120 Hz, some tube current ripple is a result of the temperature variations induced. For high frequency generators, the thermal inertia of the filament suppresses fluctuations of thermionic emission.

5.4.2. Generating the tube voltage

Irrespective of the waveform, the tube voltage is defined as the peak voltage, kVp, of the voltage train. The voltage ripple, R, is given as the relative difference of the minimum voltage, kV_{min}, from the peak voltage, $R = (kVp - kV_{min})/kVp$. In X ray units, the tube voltage is supplied symmetrically to the tube, i.e. a net potential difference of 150 kV is achieved by feeding –75 kV to the cathode and +75 kV to the anode. This is accomplished electrically by grounding the centre tap of the secondary coil of the high voltage transformer. The requirements for electrical isolation are then less stringent. In mammography with tube voltages <40 kV, and with some high performance tubes, one electrode is kept at ground potential.

Except for grid controlled tubes, the length of an exposure is determined by the provision of high voltage to the tube by switching in the primary circuit. Electromechanical relays used to be employed in single-phase and three-phase generators, but electronic switching components, such as thyristors, are now used. In single-phase generators, timing is only possible in multiples of pulses, giving inaccurate timing for short exposures. Three-phase generators use a prepulse of low current to avoid magnetic saturation of the transformer core. When the high voltage is turned off, the charge stored in the cable capacitance and the circuit is discharged via the X ray tube. The end of the voltage waveform, therefore, shows some tailing, an effect that impairs the production of short pulses.

5.4.2.1. Single-phase generators

Single-phase generators use a single-phase mains supply and a step up transformer with a fixed winding ratio. The high voltage is set by a variation of the primary voltage with a switched autotransformer. Half-wave rectification of the transformed voltage gives a 1-pulse waveform, where a pulse is a half wave per period of mains frequency (50 or 60 Hz). Some low power X ray units use the tube as a self-rectifying diode with current only flowing from the cathode to the anode, but reverse current flow, as a result of a hot anode, is a limiting factor. Nowadays, solid state diodes are used as rectifiers. A full wave rectification yields two half waves per period (2-pulse waveform). Voltage ripple of 1- and 2-pulse waveforms is 100%.

5.4.2.2. Three-phase generators

With a three-phase mains supply, three AC voltages, each with a phase shift of 120°, are available. Full wave rectification then gives six half waves per period (6-pulse waveform), with a nominal ripple of 13.4%. Owing to imbalances in transformer windings and voltages, the ripple might, in practice, approach 25%. Adding another secondary winding to the transformer gives two secondary voltages. Combining the full wave rectified secondary voltages using delta and wye connections yields a total of six phases with a phase shift of 60° each. Full wave rectification then gives a total of 12 pulses per period, with a nominal ripple of 3.4% (in practice, less than 10% is achieved). Three-phase generators are more efficient and allow for much higher tube output than single-phase generators.

5.4.2.3. High frequency generators

This type of generator includes a stabilized power supply in the front end of the device. First, the mains supply is rectified and filtered to produce a direct current (DC) supply voltage needed for an inverter circuit. The inverter generates pulses that are transformed, rectified and collected in a capacitor to give the high voltage for the tube. The inverter pulse rate is used to control the tube voltage. The actual voltage on the tube is sensed by the generator and compared with the voltage set on the console. The difference is then used to change the pulse rate of the inverter until the set voltage is achieved. Similarly, a separate inverter system is used for the tube current.

The pulse shape of a single X ray exposure pulse resembles a fundamental frequency of several tens of kilohertz, giving rise to the generator's name. Transformers for such frequencies are much smaller than for 50/60 Hz voltages, reducing the weight substantially. In low power generators, the whole generator could be included in the tube housing, avoiding any high voltage cabling.

The voltage ripple depends on many technical factors, but for low power applications it is typically ~13%, dropping to ~4% at higher currents. The time constants relevant for voltage and current control are typically <250 μs, enabling better timing control of the exposure than with single and three phase generators.