APPENDIX E

X-ray equipment operation

Introduction to X-ray equipment operation

Aim

The aim is to provide an overall view of current X-ray equipment design and operation. This information is intended to enhance the maintenance and repairs sections of this workbook, by providing a detailed examination of equipment operation requirements. In addition, to provide some of the technical knowledge required by an electrician, or electronics technician, assisting in repairing the equipment.

Object

When carrying out routine maintenance, and in particular, diagnosing incorrect equipment operation, a good knowledge of how equipment operates is required.

The material in this appendix is intended both as a revision of equipment operation, and to provide specific information of equipment internal operation. This includes operational sequence of events, and the internal tests and checks carried out by the equipment. This is also an introduction to X-ray systems for an electrician or electronics technician, who may be asked to assist in the event of a problem. The first three parts have been provided as the background for this introduction.

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PART 1 THE PRODUCTION OF X-RAYS

Contents

a. The X-ray tube
b. Bremsstrahlung radiation
c. Characteristic radiation
d. X-ray properties
e. Filters
f. Specification of minimum filtration
g. The inverse square law

a. The X-ray tube

The X-ray tube consists of an anode and cathode inside an evacuated glass envelope. The cathode is a filament, which when made very hot, emits electrons. When a high voltage supply is placed between the cathode and anode, the electrons from the cathode strike the anode, releasing X-rays. See Fig E–1. There are two main types of X-ray radiation generated: Bremsstrahlung (braking radiation) and characteristic radiation.

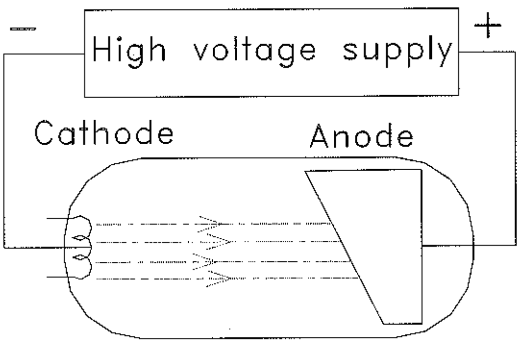


Fig E–1. The X-ray tube

b. Bremsstrahlung radiation

When an electron passes close to the nucleus of an anode atom, it is deflected, and its speed or energy reduced. At the same time, an X-ray photon is produced, which has an energy level equal to that lost by the electron. See Fig E–2. Peak X-ray energy, expressed in 'electron-volts' or 'keV', occurs only when an electron strikes the nucleus, giving up all its energy immediately. The electron will continue to pass through the anode atoms, and produce further X-ray photons. However, about 99.5% of the electron energy is lost in generating heat.

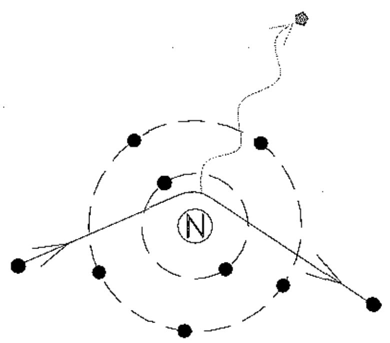


Fig E–2. Bremsstrahlung radiation

c. Characteristic radiation

This occurs when an incoming electron collides with an electron in the inner 'K' shell. To replace the missing electron, an electron moves from the 'L' shell to the K shell, giving up its energy as an X-ray photon. This has a predominant energy of 59 keV. See Fig E–3.

There are other transitions, notably from the 'M' shell to the 'K' shell (67.2 keV) and 'N' shell to the 'K' shell (69 keV). The above energy levels are specific for tungsten, and are known as 'Characteristic radiation'.

Note. To eject an electron from the K shell, the incoming electron requires energy greater than 70 kV, which is the binding energy of the K shell electron to the nucleus of a tungsten atom. Below 70 kV, radiation is entirely due to Bremsstrahlung. At 80 kV, characteristic radiation is about 10%, and at 150 kV is about 28% of the total usable X-ray beam.

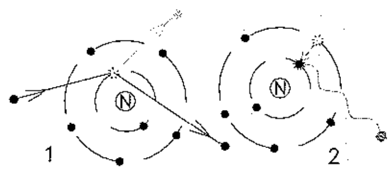


Fig E–3. Characteristic radiation

d. X-ray properties

X-ray beam quality and quantity depends on three main factors.

—The kV applied between anode and cathode
—Filtration to remove low energy X-rays.
—The amount of electron emission from the cathode, which affects quantity only.
—The film focus distance (FFD). Radiation is reduced by the inverse square law.

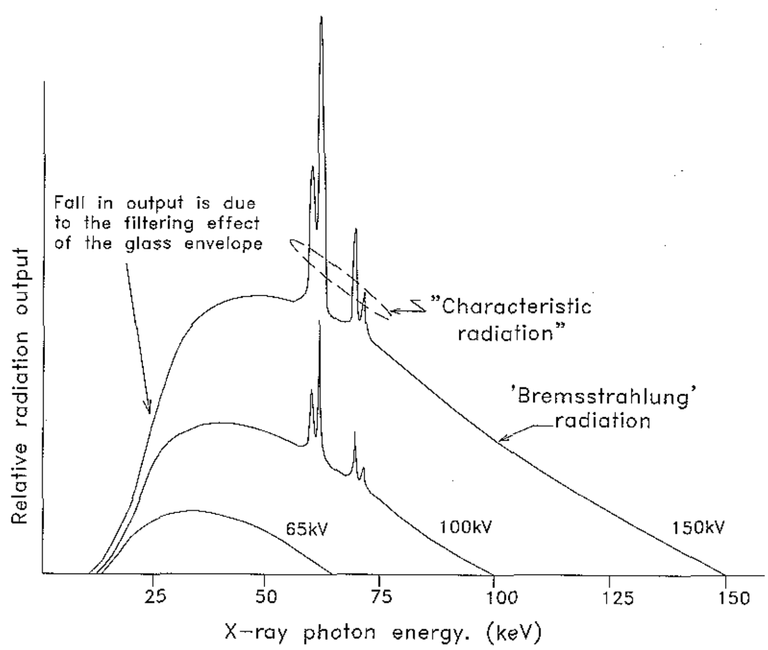


Fig E–4. Illustration of relative kV output, for three values of kV

e. Filters

X-ray photons below ~40 keV have little penetrating power in standard diagnostic X-ray procedures, and only contribute to unwanted radiation of the patient. To remove these lower energy X-rays, added filters are placed in the X-ray beam. The filter material is normally made of pure aluminium. For special applications filters made of different materials may be used. These are called 'K Edge' filters. An example of this is an X-ray tube used in mammography, which may have a molybdenum filter.

Where it is desired to make most use of low keV radiation, some collimators have a removable filter. This has a safety switch, so that if the filter is removed, X-ray generation is not permitted above a specified kV level.

f. Specification of minimum filtration

Most countries specify a minimum filtration that will be used for diagnostic X-ray. The total filtration is the combination of the X-ray tube glass, the mirror in a collimator, plus the added filter in the X-ray beam. To ensure the minimum required filtration is obtained, tables are provided for measurement purposes.

Typical half value layers are provided in table E–1. The actual specification may differ in some countries.

How to measure the half-value layer

- At a specified kV, a radiation meter measures the radiation from the X-ray tube. Added aluminium filtration is placed in the beam. The amount of aluminium to reduce the beam by 50% is called the half-value layer.
- Referring to table E–1, at 100 kV, this should require at least 2.7 mm of aluminium.
- If the specified value of aluminium reduces radiation by more than 50%, total filtration is insufficient, so more permanent aluminium must be placed in the X-ray beam.

Table E–1. Minimum half value layer, at different kV levels

X-ray tube voltage (kV)	Minimum permissible first HALF-VALUE LAYER (mm Al)
50	1.5
60	1.8
70	2.1
80	2.3
90	2.5
100	2.7
110	3.0
120	3.2
130	3.5
140	3.8
150	4.1

g. The inverse square law

The quantity of X-rays available for a given area depends on the distance from the X-ray tube. For a given distance, the X-ray beam may cover an area of 10 × 10 cm. If we double the distance the same beam will now cover an area of 20 × 20 cm, in other words, four times the previous area. However, the radiation available for each 10 × 10 cm section is now only one quarter its previous value. See Fig E–5.

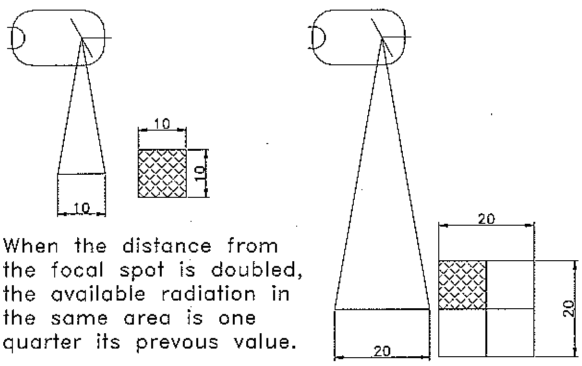


Fig E–5. Illustration of the inverse square law

PART 2 THE X-RAY TUBE

Contents

a. The stationary anode X-ray tube
b. The rotating anode X-ray tube
c. The X-ray tube housing
d. The X-ray tube focal spot
e. Anode angle
f. Maximum anode heat input
g. Anode rotation speeds
h. Effect of rotation speed on output
i. Anode heat and cooling time
j. The X-ray tube filament
k. Filament focus
l. Grid controlled X-ray tube

a. The stationary anode X-ray tube

This is usually found in portable X-ray generators, or in dental units. The anode is a small insert of tungsten, inside a large copper support. The copper is to help adsorb the heat produced. As a general rule focal spots are larger than for the rotating anode type, as the heat produced is in a very small area.

b. The rotating anode X-ray tube

By rotating the anode, the heat produced is spread around a wide area. This allows time for heat to be absorbed into the body of the anode. As a result, much smaller focal spots may be used, together with an increase in output.

Rotation is achieved by attaching a copper cylinder to the anode. This forms the 'rotor' of an induction motor. Special ball bearings are required, designed to withstand the heat from the anode. A stator winding is placed over the anode end of the X-ray tube, to form the energising section of the motor. See Fig E–7.

c. The X-ray tube housing

The housing is lead lined, so that radiation only exits via the port in front of the focal spot. This port is usually a truncated plastic cone, extending from the surface of the housing close to the X-ray tube glass. This reduces the absorption of X-rays due to the oil. Oil provides the required high voltage insulation, and serves to conduct the heat from the anode and stator winding to the outside surface. A bellows is provided to allow the oil to expand as it becomes hot. A thermal safety switch is fitted to ensure protection against excessive housing heat. In some cases, this may be a micro switch, operated when the bellows expands beyond its operating limit. See Fig E–9.

d. The X-ray tube focal spot

By focussing a vertical beam of electrons, onto the anode, which has a specific angle, an effective small area of X-rays results. This is known as the 'focal spot', and the method of generation as the 'line focus principle'.

As indicated in Fig E–10, this effective focal spot becomes enlarged as the useful beam is projected towards the cathode end of the X-ray tube. While the spot will become smaller towards the anode side, a point is reached where X-ray generation rapidly becomes less. This is known as the 'heel effect'. See Fig E–11.

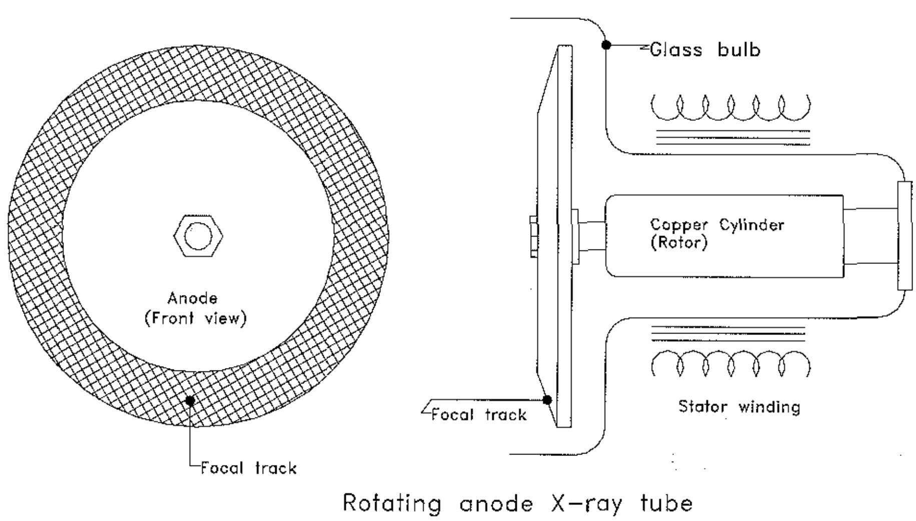


Fig E–7. Anode and motor for a rotating anode X-ray tube

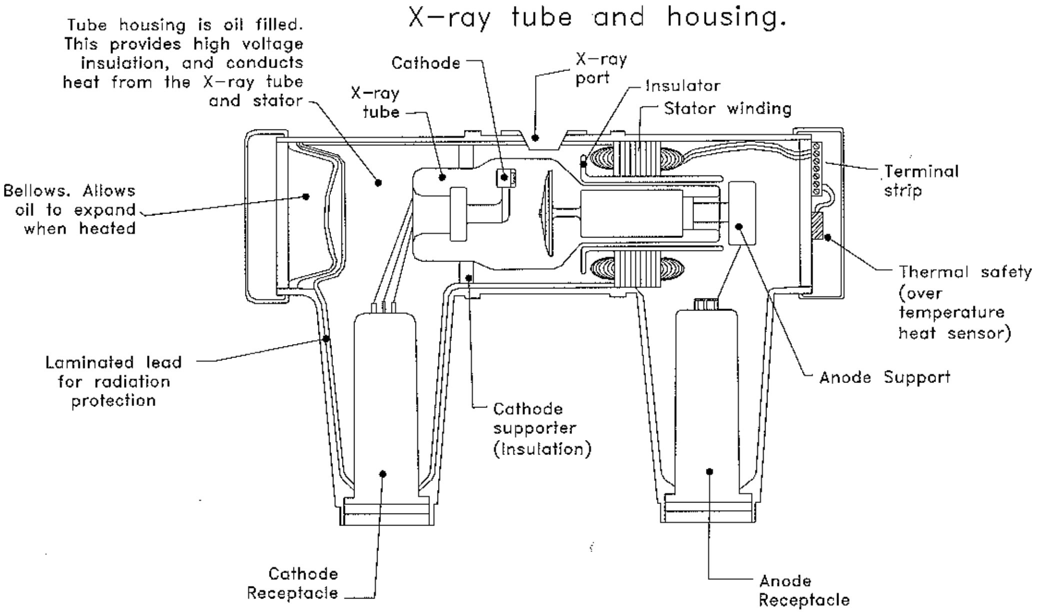


Fig E–9. The X-ray tube and housing

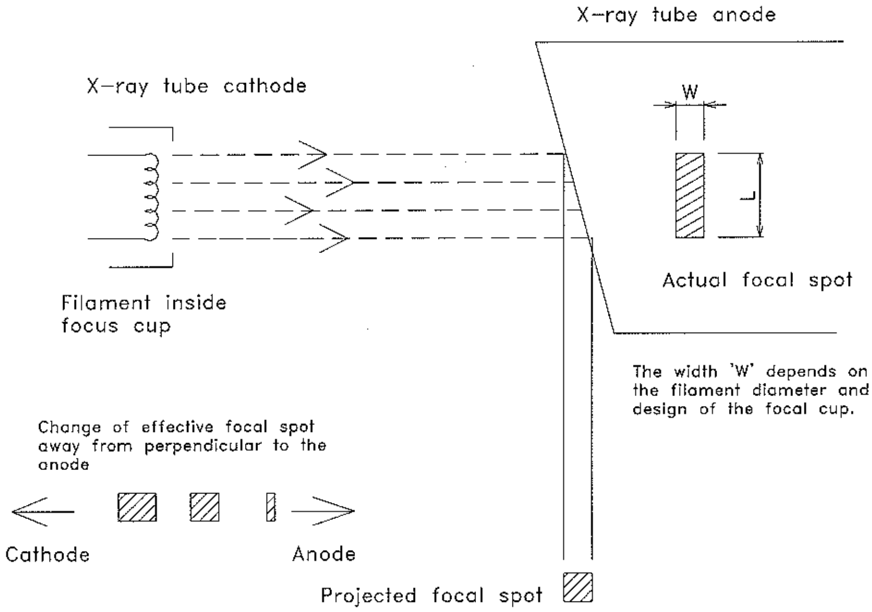


Fig E–10. Formation of the focal spot

e. *Anode angle*

The wider the anode angle, the greater will be the film coverage at a specific distance. However, to maintain the same focal spot size, the length 'L' of the electron beam must be reduced. This results in a smaller area to dissipate the immediate heat, so the maximum output of the tube has to be reduced. See Fig E–10.

A common angle for an over-table tube is 12º. An under-table tube in a fluoroscopy table may have an angle of 16º. With a 12º angle, radiation may cover a 35 × 35 cm film at a FFD of 100 cm, while a 16º angle

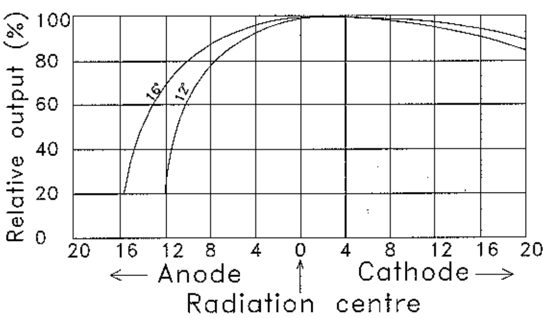


Fig E–11. Relative radiation output for two anode angles

would cover the same film at a distance of 65 cm. Fig E–11 indicates the relative radiation output for two common anode angles. The rapid fall off to the anode side is due to heel affect.

f. Maximum anode heat input

The maximum heat input for the X-ray tube anode is determined by:

- The anode material.
- Anode rotation speed.
- Anode diameter.
- Focal spot size.
- The kV waveform. (Single-phase, or three-phase)

An X-ray tube anode load capacity is rated as the number of kilowatts for an exposure time of 0.1 second. This is calculated from the rating chart for a specified mode of operation. For example, In Fig E–11a, the product of mA and kV at 0.1 second is 38 kW.

g. Anode rotation speeds

There are two anode rotation speeds in use, low speed and high speed. These depend on the power main supply frequency. High speed was originally obtained from static frequency-triplers, which generate the third harmonic of the mains frequency. Later high-speed systems use solid-state inverters, so high speed is now usually at the higher 10800 frequency, even with a 50 Hz supply.

With the simple form of induction motor used to rotate the anode, there will always be some slip, so the anode does not reach the full possible speed. The nominal speed that may be reached is indicated in brackets in table E–2.

Table E–2. Common anode speeds. The speed shown in brackets is the actual obtained speed, versus the theoretical maximum speed

Frequency	Low speed	(Low speed)	High speed	(High speed)
50 Hz	3000	(~2850)	9000	(~8700)
60 Hz	3600	(~3450)	10800	(~10500)

h. Effect of rotation speed on output

High-speed operation is of maximum benefit for short exposure times. (The generator should also sufficient output, to take advantage of high-speed anode rotation.) In Fig E–12b two load lines are indicated, one for high-speed, and one for low-speed operation. While this example is for 100 Kv operation, a similar result is obtained for other load factors.

i. Anode heat and cooling time

A stationary anode X-ray tube can have the copper section of the anode extended outside the glass container, and into the oil. This allows direct conduction of anode heat. This is not possible for a rotating anode, and heat is dissipated by direct radiation from the anode disk. Depending on anode diameter and thickness, this can take a long time time.

A typical cooling chart is provided in Fig E–13, and the formulas for calculation of the heat unit provided in table E–3.

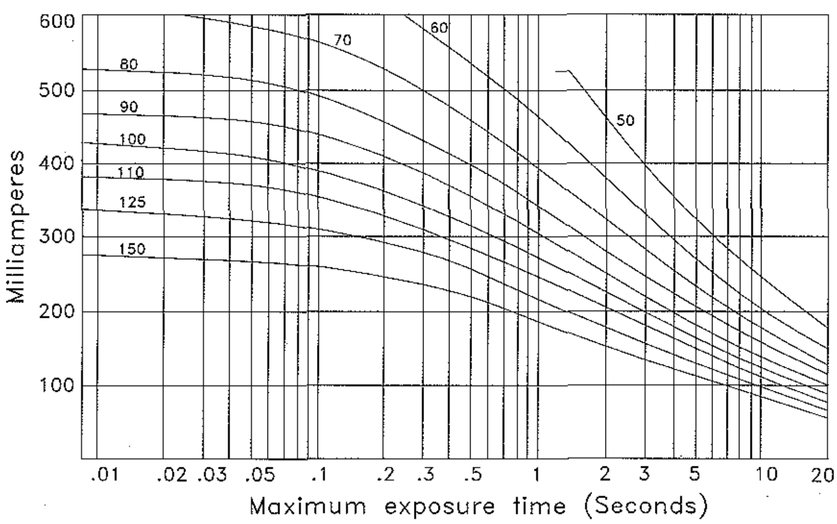


Fig E–12a. A typical anode-rating chart

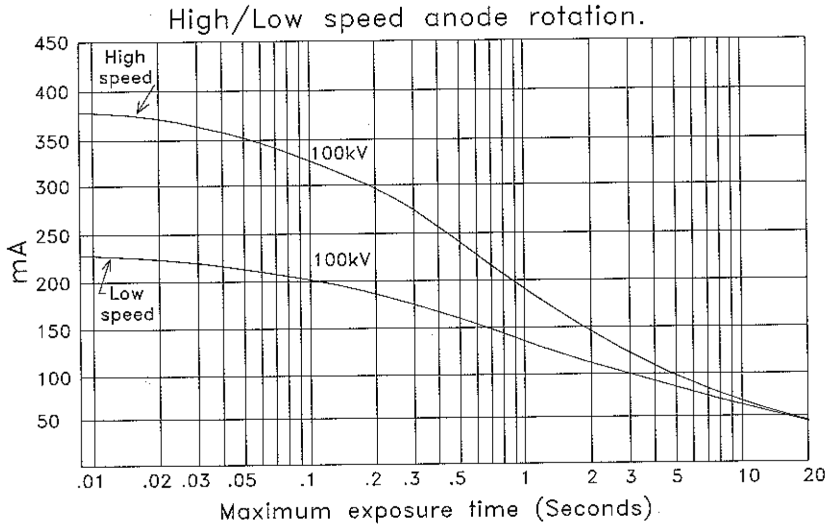


Fig E–12b. High-speed operation allows an increased anode load

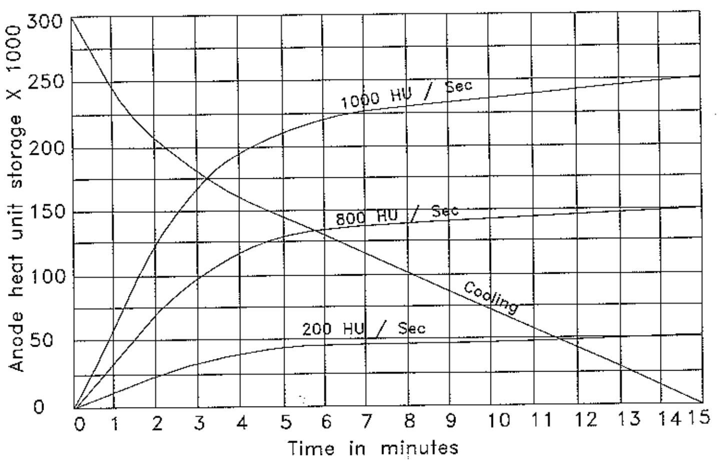


Fig E–13. A typical chart to indicate the rise in anode heat versus the cooling time

Table E–3. Formulas used for anode heat-unit calculation

kV waveform	Per exposure	Continuous
Single phase, full wave operation.	HU = kV × mA × s	HU/s = kV × mA
Three phase, full wave operation.	HU = kV × mA × s × 1.35	HU/s = kV × mA × 1.35
Medium or high frequency inverter.	HU = kV × mA × s × 1.35	HU/s = kV × mA × 1.35

j. The X-ray tube filament

To emit electrons, the filament must be brought to a white heat temperature. As the temperature increases, a point is reached where, despite further increases in temperature, only a small increase in emission results. In this area tungsten evaporation also increases, greatly reducing the filament life. This determines the maximum usable emission from the filament. Fig E–14 indicates the non-linear characteristic of the filament.

When the kV is increased, electron emission from the filament to the anode also increases. This is commonly known as the 'Space charge' effect. As an example, Fig–14 shows the change of mA that can take place as kV is increased. In this example, with a

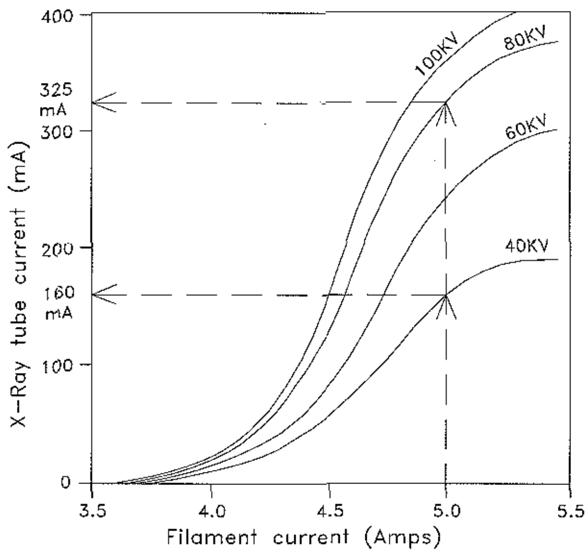


Fig E–14. A typical filament emission chart

filament current of 5.0 A, at 40 kV the emission is 160 mA, and increases to 325 mA at 80 kV. To keep mA constant, as kV is changed, the generator control must change the filament current. This is called 'space charge compensation'.

k. Filament focus

To enable a tight beam of electrons to the anode, the filament is placed inside a 'focus cup'. The focus cup is connected directly to the common centre point of the cathode.

Normally the two filaments are placed side by side, and angled, so to strike the same anode position. Some designs instead have the filaments placed end. This allows formation of two separate tracks on the anode. These tracks can have separate angles to suit the required application. There is, however, a problem with two separate tracks, as exact alignment of the collimator to both tracks is not possible.

l. Grid controlled X-ray tube

In this design, the focus cup is brought out to a separate connection. By applying a strong negative voltage between the focus cup and the filament, electron emission is suppressed.

With this change of connection, the cathode cup is now referred to as a 'grid'. Grid control allows control of the X-ray exposure, while high voltage is continuously applied between anode and cathode. In operation, the grid is kept negative with respect to the filament, until an exposure is required. During an exposure, the negative voltage is removed, permitting emission from the filament. To terminate the exposure the grid is again made negative in respect to the filament.

Grid control may be used where rapid precise exposures are required, such as in special procedure rooms. However the most common use of grid control is in capacitor discharge mobiles.

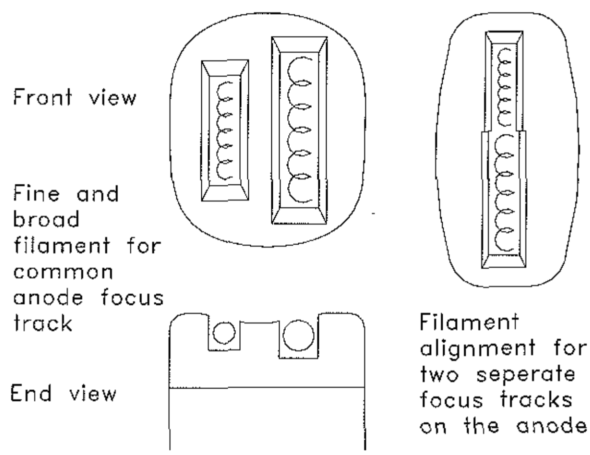


Fig E–15. Two versions of filament design for the cathode

PART 3 HIGH VOLTAGE GENERATION

Contents

a. Single-phase, self rectified
b. Single-phase, full-wave rectified
c. Three-phase generators
d. Three-phase 'Six Pulse' generator
e. Three-phase 'Twelve Pulse' generator
f. The 'Constant potential' generator
g. High-frequency generators
h. The capacitor discharge (CD) mobile

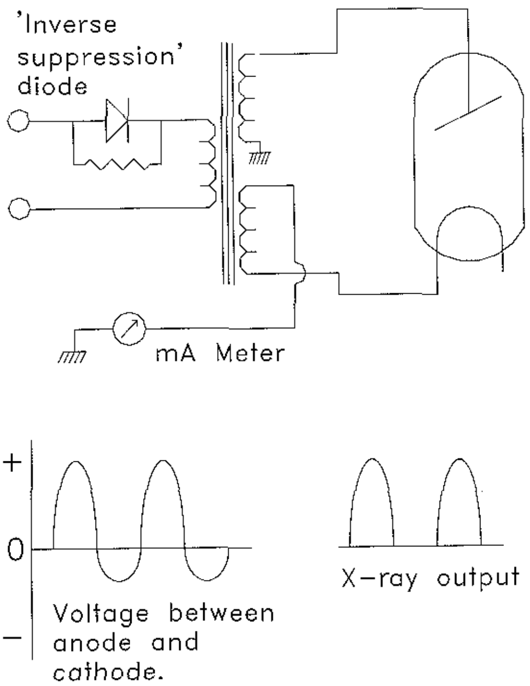


Fig E–17. Single-phase self-rectified generator

a. Single-phase, self rectified

The X-ray tube can also be considered as a rectifier, in that electrons emitted from the cathode filament travel to the positive anode. If the anode is negative in respect to the cathode, no electron flow occurs.

However, in case the anode is very hot, electron emission can also occur from the anode, in which case electron flow can exist from the anode to the cathode. This is called 'back-fire', and would damage the filament. To prevent this, an external diode and resistor is fitted to the primary of the HT transformer. The effect is to greatly reduce the available high voltage on the negative half cycle. This is called 'inverse suppression'.

The high-tension winding is 'centre tapped', so that both anode and cathode have equal voltage applied above ground potential.

Single phase self rectified systems are normally found in small portable X-ray generators, or may be used in dental units. Efficiency is low, and long exposure times will be required.

b. Single-phase, full-wave rectified

Full wave rectification results in both half cycles of the ac voltage used for X-ray production. There is no danger of back-fire, as no negative voltage is applied to the anode. Much higher output is now available. Full wave rectification is used on systems ranging from portable, dental, mobile, and up to heavy duty fixed installations. While self rectified generators may have a maximum output of 10–15 mA, full wave rectified units have been produced with up to 800 mA output.

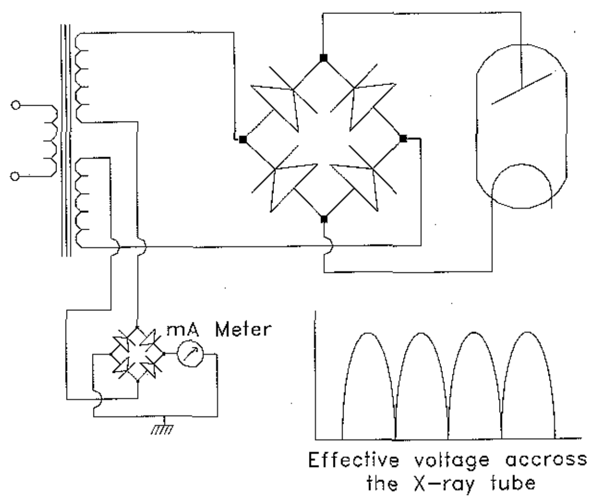


Fig E–18. Single-phase full-wave generator

The high-tension winding is centre tapped, with the centre position connected to ground. This ensures anode and cathode voltages are equally balanced above ground potential.

As the current in the transformer winding is AC, an additional rectifier is required for the mA meter (normally mounted on the control front panel). Exposure times are in multiples of the power main supply frequency. For a 50 Hz supply, exposure time calculation is simple. See table E–4.

With a 60 Hz supply, each pulse is 8.3 milliseconds wide. So some generators may indicate exposure times below 0.1 second as a number of pulses, rather than a set time.

Table E–4. Indication of exposure time for a single-phase, 50 Hz generator

50 Hz supply	10 milliseconds for each 'pulse'	0.01 second exposure = 1 pulse.	0.05 second exposure = 5 pulses	0.2 second exposure = 20 pulses

c. Three-phase generators

By operating with three-phase power supply, several advantages occur:

- The peak power demand per phase is reduced, with the input power equally shared between all three phases.
- Rather than pulsed high voltage, the X-ray tube now has continuous voltage supplied, so radiation for a given kV and mA is considerably greater. This results in shorter exposure times for a given setting, while the radiation absorbed by the patient is also reduced.
- Shorter exposure times, down to 0.003 seconds, are available. Exposure time calculation for 60 HZ is more accurate.
- The X-ray tube has higher anode load capacity for short exposure times, although for long exposure times this will be less.
- Three phase generators have typical outputs of 500 mA up to ~1200 mA.

d. Three-phase 'Six Pulse' generator

This system uses an identical style of winding for both the anode and cathode side. The windings may be configured 'star' or 'delta'. The system obtains its name due to the six joined together pulses that are generated each cycle. The 'ripple factor' for six-pulse is ~13%.

In the example shown below, the secondary windings are both delta configuration. The two isolated sets of windings and rectifier systems allow independent voltage supply to both anode and cathode. By connecting the common centre point to ground, both anode and cathode are equally balanced above ground.

See Fig E–19.

e. Three-phase 'Twelve Pulse' generator

With the twelve-pulse generator, one winding is configured delta, and the other star. The voltage peaks between these two windings have a 30 degree phase-shift, so that a peak of the rectified output from the delta winding will coincide with a trough from the star rectified output. This result in twelve joined together pulses for each cycle.

The overall ripple-factor is considerably improved, to a possible 3.5%. This improved ripple factor allows higher effective radiation output for a set kV, compared to six-pulse generators. With special exposure contactor systems, exposure times down to 0.001 seconds have been achieved. Conventional exposure contactors however, have the same exposure time limitations of the six-pulse systems.

See Fig E–20.

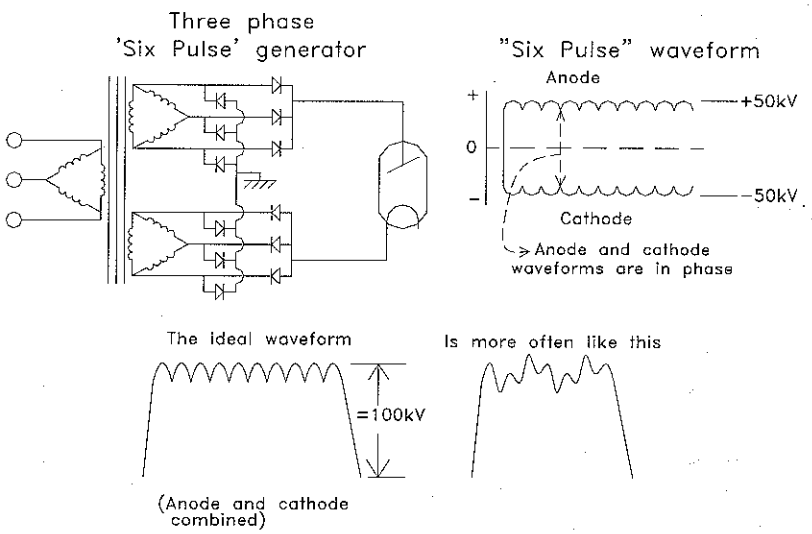


Fig E–19. Three-phase, six-pulse generator

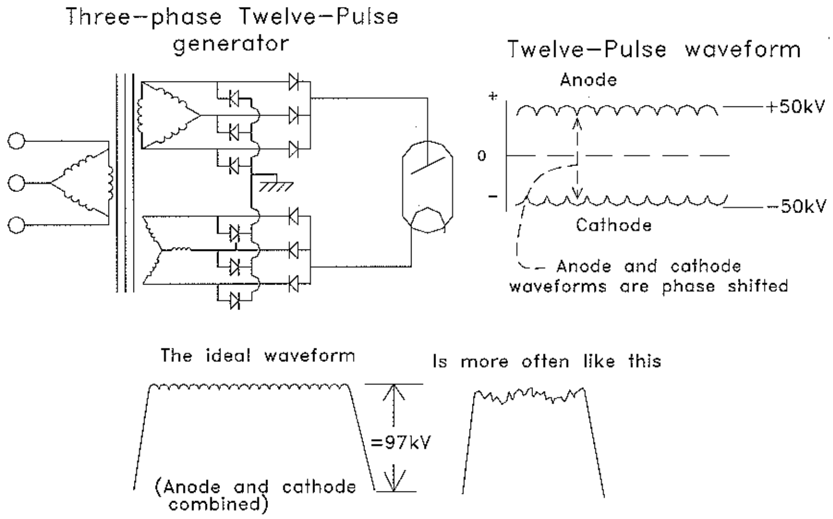


Fig E–20. Three-phase twelve-pulse generator

f. The 'Constant potential' generator

With this generator, there is NO ripple factor, and the voltage applied to the X-ray tube is pure DC. To achieve this, the output of a conventional six-pulse generator is smoothed by high voltage capacitors. The high voltage is then passed through a pair of high voltage tetrode valves. These serve to control the exposure, and regulate the actual high voltage supplied to the X-ray tube.

To achieve good regulation, the high voltage obtained from the generator is set about 50 kV higher than actually required. During the exposure, the tetrodes control the voltage at the required level to the X-ray tube. Constant-voltage generators were used for special procedure rooms, and CT scanners. The construction and maintenance of these systems is expensive. They have been largely replaced by high-frequency inverter systems. However, they are still in use for providing a very accurate X-ray calibration standard.

g. High-frequency generators

These are sometimes known as 'medium frequency' generators, depending on the maximum frequency of the inverter.

Generally, if maximum frequency is below ~20 kHz, the generator is called 'medium frequency'. Current high-frequency generators can operate up to 100 kHz, although most systems will operate below 50 kHz.

Inside the high-frequency generator, the AC mains power is rectified, and smoothed by a large value capacitor, to become a DC voltage supply. The 'inverter' converts the DC voltage back into a high-frequency AC voltage. This in turn is fed into the primary winding, of the high-tension transformer.

High-frequency generators have many advantages over conventional generators, operating at 50 or 60 Hz power main frequency.

- The high-tension transformer now uses ferrite instead of an iron core, with an increase in efficiency.
- The required inductance of the transformer winding is reduced, resulting in a big drop of copper resistive loss, again improving efficiency.
- Transformer manufacturing costs are reduced.
- High-voltage output is tightly regulated, so normal changes in power main voltages have no affect on the exposure.
- The high-voltage waveform is similar to between an ideal six-pulse to twelve-pulse generator for a medium-frequency system. A high-frequency generator waveform has less ripple, in many cases less than 2%. However, final ripple depends on other design considerations.
- High-voltage production is highly consistent, with little variation in residual kV ripple. (Unlike three phase systems, this can suffer distortion of the kV waveform.)
- Used in a mobile system, the inverter may operate directly from storage batteries, or else from large capacitors charged via the power point. In both these cases, kV waveform remains similar to large fixed installations.
- While earlier medium frequency systems had high development costs, present high-frequency systems are more cost effective than conventional generators.

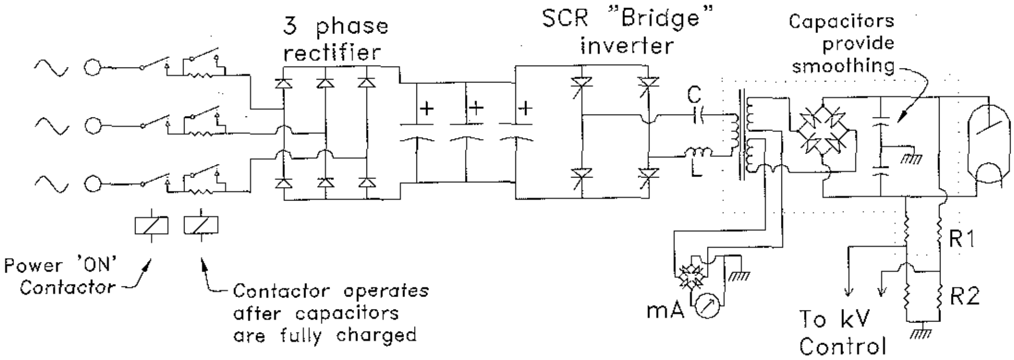


Fig E–21a. Diagram to illustrate the principle of a high-frequency generator

- On initial power up, a resistor limits the charging current of the capacitors. This is necessary, as otherwise with the capacitors discharged; it would be equivalent to placing a short circuit on the output of the rectifiers.
- After the capacitors are charged, another contactor shorts out the resistors. The system is now ready for operation.
- The energy stored in the capacitors supplies the high peak current required by the inverter.
- The inverter illustrated is an SCR 'bridge' inverter. The output of this inverter is coupled via a resonant circuit to the primary of the HT transformer,
- The capacitor 'C', and the inductance 'L', together with the inductance of the transformer winding form a series resonant tuned circuit. The resonant circuit has two functions.
  —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.
  —The resonant circuit has a 'flywheel affect', so that on the reverse half cycle, the back EMF attempts to reverse the current in the pair of SCRs that produced the initial pulse. This causes that pair to switch off. (The other pair will produce the next pulse, but this time in the opposite direction)
- The high-tension transformer is operated similar to a single-phase generator, with two exceptions.
  —For medium-frequency generators, added capacitors to provide waveform smoothing. For many high-frequency generators however, the inherent capacitance 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 to a reference voltage equivalent to that for the required kV. If there is any difference, the inverter control circuit changes the pulse rate to correct the error. This is called 'closed loop' or 'feedback' regulation.

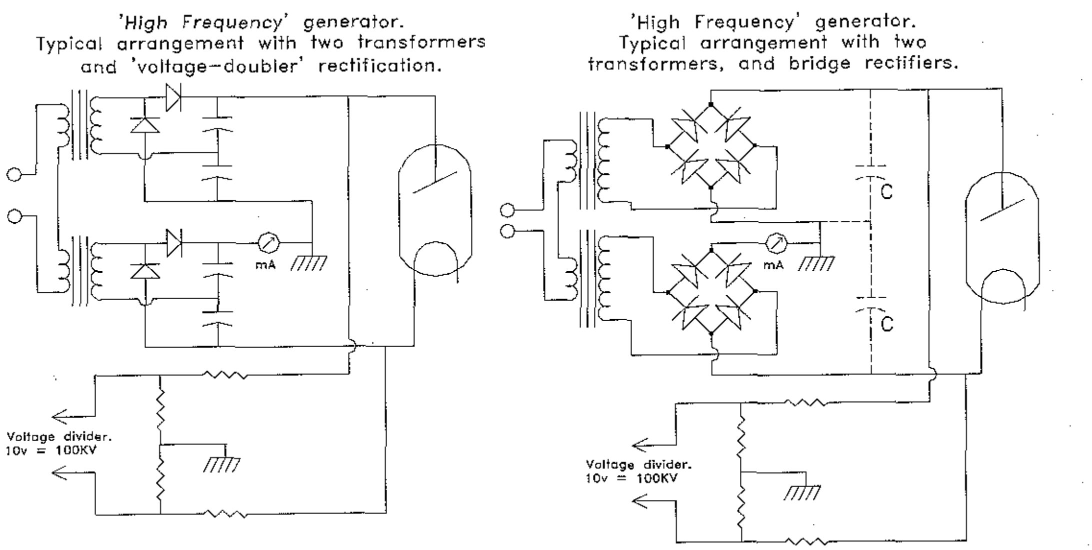


Fig E–21b. Two versions of high voltage generation, used with a high-frequency system

h. The capacitor discharge (CD) mobile

The capacitor-discharge or 'CD' generator obtains high voltage for an exposure directly from a pair of capacitors. These are charged to the required kV before making an exposure. As the kV for an exposure is applied to the X-ray tube prior to an exposure, a 'grid controlled' X-ray tube is fitted. A negative voltage applied between the 'grid', or focus-cup, and the filament. This prevents an exposure until the negative voltage is removed.

Although there is a slow capacitor charging time, the capacitor can rapidly discharge through the X-ray tube, with peak mA currents up to 500 mA. Actual peak mA depends on the X-ray tube used, not the capacitor system. During an exposure, the charge on the capacitor drops by 1 kV per mAs.

Operation

- The high voltage capacitors are charged prior to preparation for an exposure. This may take up to a *minute depending on the kV setting required.* A resistor in series with the transformer primary limits the charging current, allowing operation from a standard power point.
- The CD mobile has two capacitors, connected in series, with the common point connected to ground. This ensures the high-voltage to anode and cathode of the X-ray tube is equally balanced above ground potential. The capacitors are usually each of two microfarads capacity, and as they are connected in series, make up a total value of one microfarad.
- The transformer secondary and rectifiers are connected to the capacitors to form a 'voltage doubler'. On the positive half cycle D1 conducts, charging C1. On the negative half cycle, conduction is via D2, charging C2. The charge on C1 and C2 add together to produce the total kV available for an exposure. **See Fig E–22.**
- The resistors R1 and R2 provide a voltage measurement for the charging circuit, and for the kV meter.
- At the start of an exposure, the mAs timer operates a high voltage relay. This removes the negative voltage applied between grid and cathode. At end of the exposure, the relay stops operating, and the negative voltage is once more applied to the grid.
- Once the capacitors are charged to the required kV, the charge will slowly drop, partly due to the conduction of the kV measurement resistors, and partly due to a small 'dark current' current of the X-ray tube. (This term is used to describe conduction with a cold cathode filament.) As a result, when the kV drops a small amount, the charging circuit will again operate, 'topping up' the charge on the capacitors. Topping up is disabled during an exposure, and recharging occurs only after the charge button is again pressed.
- Due to dark-current, a very small emission of X-rays will be produced once the capacitors are charged. To prevent external radiation, the collimator is fitted with a motor or solenoid operated lead shutter. This shutter blocks all radiation, and is only opened just prior to a radiographic exposure, or at start of preparation for an exposure. Sometimes after charging the capacitors, a reset to a lower kV may be required. This is performed by a low mA exposure. During this time, the collimator lead shutter remains closed.
- The CD mobile on preparation will operate anode rotation and filament boost as for a standard generator. The filament however does not have pre-heating, as this would increase leakage current through the X-ray tube during standby.
- Control by time and mA selection is not practical, as the starting mA depends on kV selected, and falls during the exposure as kV drops. For this reason direct measurement of mA to operate a mAs timer is required.

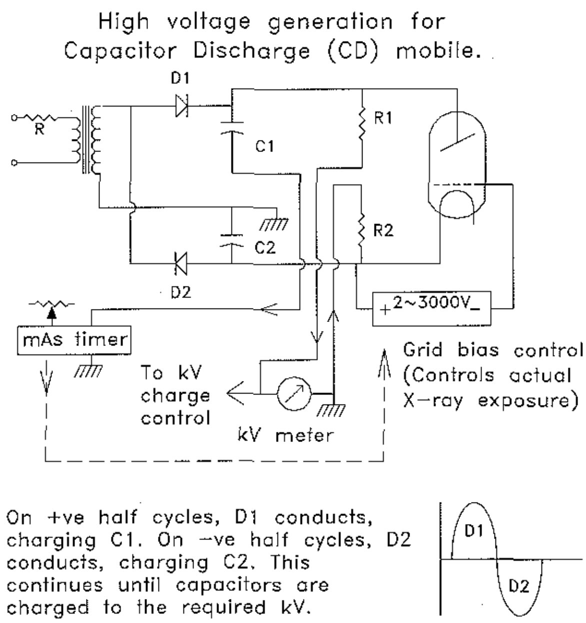


Fig E–22. The capacitor discharge generator

Relation between kV and mAs

As sown in Fig E–23, a 30 mAs exposure will cause the kV to reduce by 30 kV. As the quantity of radiation from an X-ray tube is controlled as much by kV as mAs, large mAs exposures are not practical. For example, if the above example were for 40 mAs, the last 10 mAs of the exposure would be from 60 to 50 kV, and have little effect.

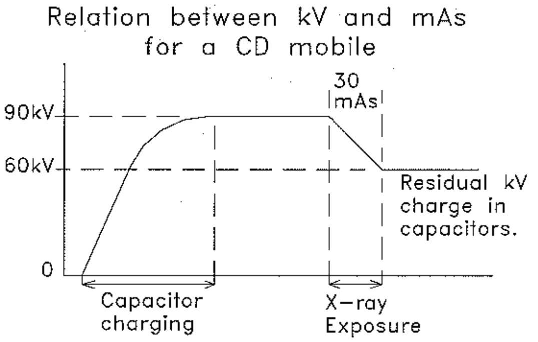


Fig E–23. Relation between kV and mAs, CD mobile

PART 4 THE X-RAY GENERATOR CONTROL UNIT

Contents

a. X-ray control functions
b. High-voltage control and load compensation
c. mA control
d. X-ray radiographic timer
e. Automatic exposure control (AEC)
f. Fluoroscopy timers
g. Exposure contactors
h. X-ray tube anode rotation
i. X-ray tube load calculation
j. Operation sequence control
k. Fault detection and safety systems

a. X-ray control functions

The X-ray control provides the following functions for radiography

- Radiographic kV selection.
- High-voltage load compensation. (For different mA outputs)
- Mains-voltage regulation. (May not be required for most high-frequency generators.)
- X-ray tube filament heating and space-charge compensation for each X-ray tube focal spot, and mA station selection.
- Selection of required mA output.
- Selection of X-ray tube focal spot. In some systems, this is automatically linked to the required mA position.
- Exposure timer. For single and three phase systems, the timer must be synchronized to the mains power supply.
- Exposure contactor, to connect the HT generator to the preselected primary voltage.
- Anode rotation control (or starter). Some systems allow for operator selection of low or high speed.
- X-ray tube safety calculation. Basic requirement is anode load and maximum kV. Calculations may also include maximum filament heating, stored heat in the anode, and a safety factor for multiple exposures.
- Technique selection of external equipment. Eg, table Bucky, vertical Bucky, tomography, etc.
- Operation sequence timing and control. Eg, after the preparation time delay, X-ray exposure request is sent to the Bucky; signal returned from the Bucky starts the exposure.

- Safety provision for operator error, radiation 'ON' warning light etc.
- System fault detection, both prior or during an X-ray exposure.

The following additional functions are provided for fluoroscopy

- Fluoroscopy kV selection
- Automatic fluoroscopy-kV control. (May be an option)
- Fluoroscopy mA control. Depending on the design, this may be not available for the operator. Instead the level of mA may be controlled directly by the fluoroscopy kV selection.
- Fluoroscopy exposure timer. Depending on system design, this may either stop exposures, or just sound an alarm; after a maximum accumulated time (normally five minutes) has expired.

The control may have these optional features

- Automatic exposure control, or 'AEC'. Often known as 'photo timer', and sometimes by the Siemens title of 'Iontomat' or Philips title of 'Amplimat'. The AEC measures the quantity of radiation as it enters a cassette. This measurement is used to control the exposure time.
- Anatomical programmed radiography or 'APR'. APR is a system of preset exposures, depending on the area of the body to be examined. Current systems, with microprocessor controls, allow a high degree of flexibility, and may be treated as a pre-programmed exposure memory system.

b. High-voltage control and load compensation

Adjustment of high voltage for conventional systems is by preselection of the primary voltage. This voltage is sent to the primary of the high-tension transformer, when an exposure is made. This preselection of primary voltage must allow for voltage drop in the generator transformer, as well as the power mains voltage falling when under load. As we change the selection of mA, this also changes the amount of voltage drop that will occur. To compensate, as we increase the mA selection, so we must also increase the primary voltage to keep the previous kV selected correct.

Fig E–24 illustrates the relation between kV, mA, and primary-voltage for a single-phase 400 mA generator. Example: If 80 kV at 200 mA were required, the voltage for this exposure would be preset at 114 V. However, if 400 mA were required instead, then the voltage would be increased to 134 V.

- In the example shown in Fig E–25, a simple method is shown to achieve load compensation. This method may be used for a portable, or mobile, X-ray generator.
- A line voltage adjustment switch allows compensation for different input voltages. The switch is adjusted until the voltmeter is on a calibration mark. If the meter is not set to this mark, than kV will not be correct.

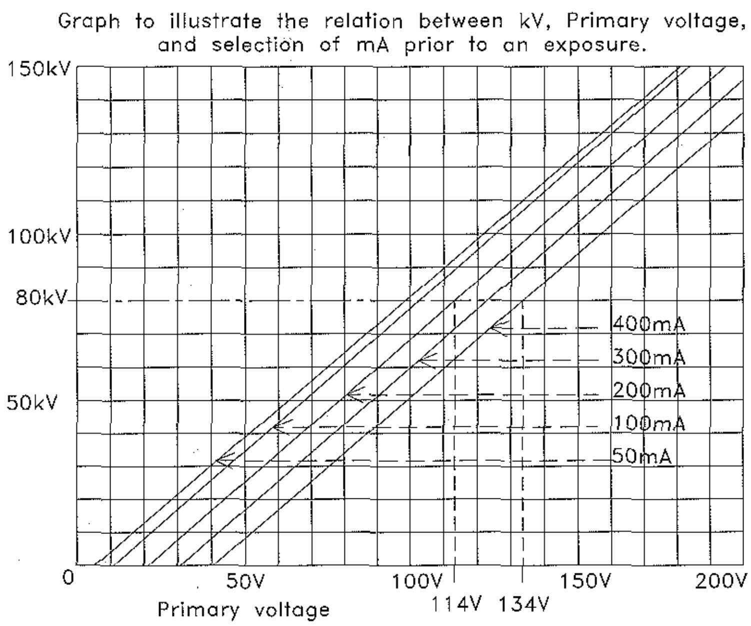


Fig E–24. Load compensation requirement as mA is changed. If 80 kV is required, then primary voltage should be 114 V for 200 mA, or 134 V for 400 mA

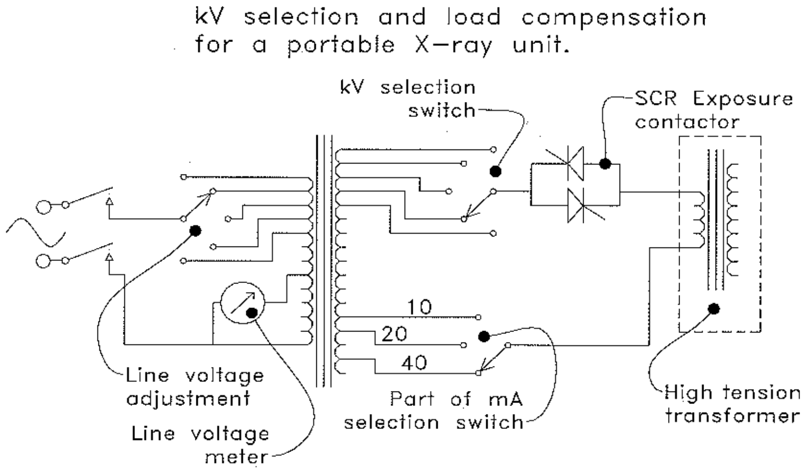


Fig E–25. High-voltage selection, and load compensation, for a portable X-ray generator

- The kV selection switch is set to the required kV.
- On selection of the required mA position, a section of the mA selector switch selects the required load compensation voltage.
- This method may be also used for larger fixed installations. More complex compensation is then applied to allow for mains supply impedance etc.

Another method is to indicate the preselected primary voltage on a voltmeter directly calibrated in kV. These systems often have two kV selection switches, one for coarse settings of about 10 kV, and the other for fine settings of 1 kV. (Although a large multi-step switch may be used instead.)

On selection of a different mA station, the meter will either increase or decrease its indicated kV, depending on the change of mA. By resetting the kV selection switches so the meter again reads the required kV, load compensation is achieved.

A similar method to the above is a scale calibrated in kV, and a pointer moved by the kV selection knob. On selection of each mA station, a different kV scale is brought into view on the control panel. (The mA selection switch also selects the required load compensation, as shown in Fig E–25.)

Many X-ray controls, especially three phase versions, have motorized 'servo' controlled selection of kV, and automatic line voltage compensation. These often use graphite rollers moving along a 'step-less' transformer winding. (Eg, the roller passes along individual turns on the outside of the transformer, making direct contact with each turn as it moves.)

Servo systems measure the voltage as the rollers pass along the transformer, and compare the voltage obtained to a required value. This value is the required kV to be generated, plus an additional voltage for load compensation. For automatic line voltage regulation, the obtained voltage is simply compared to a fixed reference voltage. In both cases, when the required voltage is obtained the servo motor is stopped. On preparation or on making an exposure, these motors are locked out to prevent movement when the mains supply voltage drops.

High frequency generators control kV by comparing directly the actual kV across the X-ray tube with a reference voltage set by the required kV. For example, if the operator selected 80 kV, the reference voltage may be 8 V. On start of the X-ray exposure, the voltage at first on the X-ray tube will be 0 kV. Very rapidly, it will approach 80 kV, at which point the measured voltage from the generator will match the reference voltage of 8 V. However, as the required kV becomes close to 80 kV, the inverter will reduce its output, so that as 80 kV is actually reached, inverter output is regulated to maintain 80 kV precisely.

High-frequency generators are not affected by mains supply voltage drop during an exposure, due to the self-regulating closed-loop mode of operation. However, some systems do require automatic mains voltage regulation, as well as correct mA calibration, to ensure kV generated at the start of the exposure is correct, and does not 'overshoot'.

Fluoroscopy control by comparison to radiographic control is much simpler, as no load compensation is required. On older systems this may be via a switch selecting 10 kV steps, or by a sliding contact on a circular 'step-less' transformer (sometimes called a 'variac').

Some generators may employ electronic control of kV, using the properties of the SCR radiographic contactor. By this method the effective voltage to the transformer primary is controlled by changing the timing pulses to the SCR contactor. In effect this is a high power version of a lamp dimmer.

With high-frequency systems, control is similar to radiographic output; however in some systems the resonant frequency of the inverter system may be raised, to reduce audible noise.

Automatic fluoroscopic kV may be obtained by having a motor drive or else by direct control of the SCR or inverter as previously mentioned. The control signal may come directly from a TV camera, or else via a photomultiplier sampling the light directed to the TV camera. Automatic fluoroscopic kV control is used to optimise the light level into the camera, as well as avoiding excessive radiation to the patient.

c. mA control

The control of X-ray tube emission, expressed in milliamperes or 'mA' requires consideration of several factors. In particular, the level of filament heating to obtain the required emission, and the affect of generated kV on actual emission.

The following requirements need to be considered.

- Filament current to obtain the required mA emission level.
- Modify the filament current as the set kV, before an exposure, is selected. This is to ensure emission is constant over the range of available kV, and is called 'space charge' compensation. See Fig E-27.
- Provide a level of 'pre heating' so the filament will quickly reach the required temperature during radiographic preparation. The filament may be preset to half the radiographic current in stand-by mode, or in some systems, adjusted to the point where emission would just occur. (~1.0 mA) Additional boost may be applied for quick heating during preparation. This is called 'flash' boost. However, some systems only provide pre-heating for a fluoroscopy tube, and rely on longer preparation time for the over-table tube. See Fig E-28.
- The power supply for filament heating must be well regulated, so that a drop in power mains voltage does not affect heating level. Earlier systems used a 'Constant voltage' or 'Ferro resonant' transformer for this purpose. Later systems use electronic regulation, which precisely measures and controls the current through the filament. This is done by monitoring either the current through the filament transformer primary winding, (constant current), or the voltage across the same winding, (constant voltage).
- Provide protection so the filament is not overheated. On earlier generators, no protection was provided. Later systems included protection in X-ray tube overload calculation. Present microprocessor controlled systems can have elaborate protection circuits.
- The mA control has a safety system to prevent an exposure, in case filament heating is incorrect. For example, if the filament has become disconnected due to a faulty high-tension cable, or in case the filament is broken. *In this case, there would be no load on the high-tension transformer, and the generated kV could become dangerously high.*
- Compensation for drop in mA output during exposure may be provided. As electrons are attracted away from the filament, the filament temperature falls a small amount. This effect is more noticed as the filament reaches the non-linear section of its operation. Many systems now provide feedback or closed-loop compensation for this effect. By sampling the mA generated during an exposure, comparing it to a reference level set for each mA station, a correction factor is applied to filament heating. Some microprocessor systems use this technique to automatically re-calibrate the filament control, by memorizing the final required value of filament heating.

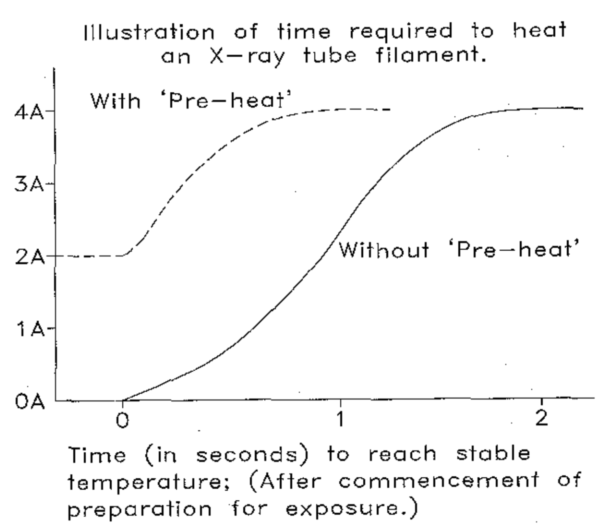


Fig E-26. Comparison of filament heating time. With and without pre-heat

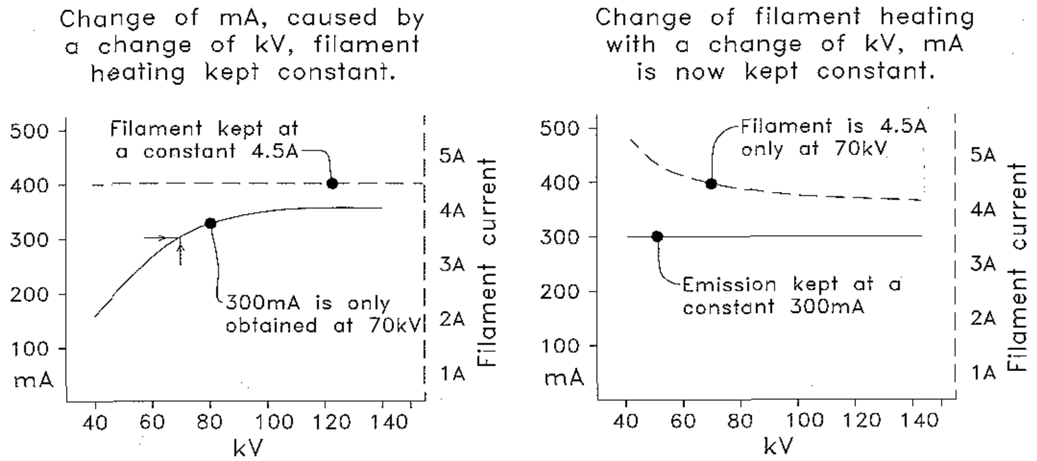


Fig E–27. These two graphs illustrate the need to modify filament heating, as kV is changed

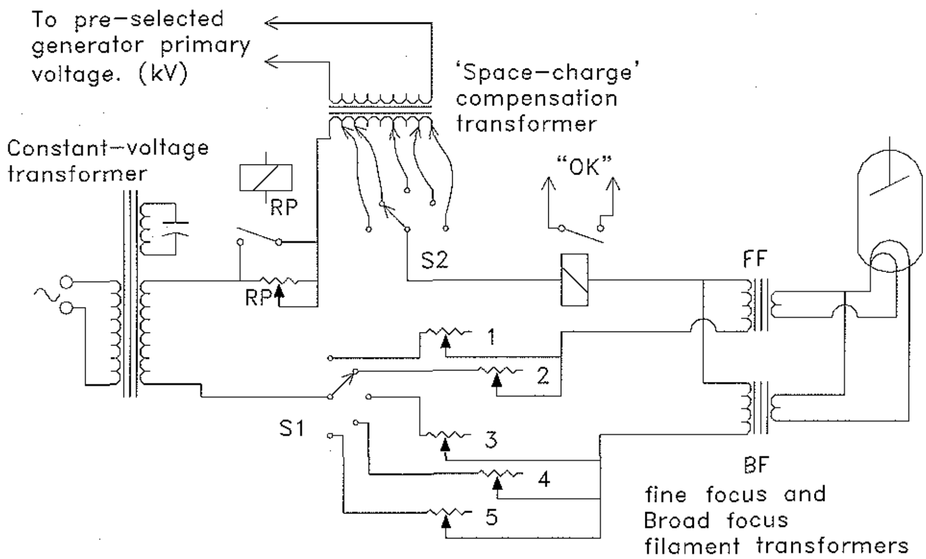


Fig E–28. A basic filament control system

The circuit in Fig E–28 has the following points of interest.

- The switches S1 and S2 are coupled together.
- S1 selects the calibration resistor for filament heating and the change over from fine-focus to broad-focus.
- S2 selects the degree of correction voltage for space-charge compensation. Although not shown, the primary of this transformer is connected so as to reduce filament heating above 70 kV, and increase filament heating below 70 kV. Taps are provided to select the correct amount of compensation for each mA position.
- The resistor RP provides reduced current through the filament transformers for pre-heating. On preparation, the contact of relay RP shorts out resistor RP, providing full radiographic heating.
- The relay and contact marked 'OK' is for filament safety. This relay is a current operated version, and if the filament is broken, or has a bad connection, the relay does not operate. This prevents the control entering the 'ready for exposure' mode.
- The two filament transformers, broad and fine focus, are mounted inside the high-tension generator tank.

Filament control systems have had considerable development since the basic method described in Fig E–28. The heavy-duty resistors were replaced with transistors, and the constant-voltage transformer is no longer required.

- Further development saw the use of highly regulated DC power supplies and a low frequency 'square wave' inverter powering the filament transformers. Such systems monitor either the current through the transformer primary or the voltage across the primary winding. This is compared to a reference voltage for each mA station, and in turn regulates the DC voltage supply to the inverter. Electronic generation of the space-charge compensation allowed an optimum kV relation to be generated. Calibration is usually carried out by small preset potentiometers and in some cases by direct output from a microprocessor. In this case the control voltages are obtained via a digital to analogue (D/A) converter.

- Current systems now tend to use high-frequency inverters, where the operation mode of the inverter itself is controlled to provide the required filament heating. This eliminates the need for a regulated DC supply to the inverter. Control is often via a microprocessor, again using a D/A converter. Filament calibration may be performed manually, by entering calibration settings at designated mA and kV positions. Some microprocessor controls also feature automatic calibration when in a service mode. In this mode the control automatically steps through a series of test exposures, and stores in memory the required data. This feature depends on the design philosophy of the manufacturer.

d. X-ray radiographic timer

The X-ray timer has several functions

- Accurate timed exposures.
- Synchronize start and stop of exposure to mains supply frequency, so the start of the exposure is achieved at 'zero crossing' of the AC power waveform. (Not required for high-frequency systems.)
- For three-phase systems, provide timing signals so each of the three phases will be connected at the correct phase interval. (Not required for inverter systems.)
- For single and three-phase systems, provide a 'phase memory', this is required for exposures that are uneven multiples of the power mains frequency. Eg, as an example 0.03, 0.05, 0.07 seconds. (Other systems may instead use two-stage power switching via a damping resistor, or else pre-magnetize the transformer iron-core by a DC current prior to exposure.)
- Supply the preset exposure time to the X-ray tube load calculation.
- Provide time settings for a safety 'backup' timer. This timer is normally a separate system, set to a little longer time than the exposure timer. If the generator is still producing high voltage after the backup time, the safety system stops the exposure by operating a safety contactor.

Timers with thyratron valves

- These are only on quite old systems, however, many are still in use.
- The thyratron valve may look like an ordinary valve, in that it has a cathode, control grids, and anode. The electrical symbol is also similar, except for a round dot indicating it is gas filled.
- The thyratron may be considered an electron relay, as conduction does not commence until a negative grid voltage is reduced below a specified level. In which case full conduction occurs, and remains conducting until the voltage between anode and cathode is removed or reverses itself. Conduction current is high, and enables the thyratron to directly operate relay coils, and in some cases, large contactors.
- In a thyratron timer, a capacitor is pre-charged to a high negative voltage. The time selector switch, via the exposure start relay, places a selected resistor across this capacitor, which starts to discharge. The time of discharge is controlled by the resistor value. When the negative voltage drops to the required value, the thyratron fires, and operates a relay to end the exposure.
- Thyratron timers have at least one adjustment to control calibration of exposure times. For example, to adjust the timing-capacitor charge voltage. There may be other adjustments, to adjust the pull in or drop out times of the exposure contactors. This ensures start and finish of an exposure is at zero crossing of the primary voltage. (If not correct, severe arcing of the contactor may occur.)

'Solid state' analogue timers

- The thyratron timer is an early version of an analogue timer. In the solid-state version, a capacitor is charged at a pre-determined rate, until the capacitor voltage reaches the level of a comparison voltage.
- The rate of charge of the capacitor is determined by the resistor value selected by the timer switch. Once the capacitor is charged to the comparison voltage, the timer removes the enable signal to the exposure contactor. In this case, this contactor is most often a 'silicon controlled rectifier' (SCR) system, however it might be a mechanical contactor in older systems.
- These timers usually have two adjustments. One adjustment is for the reference voltage, which acts

a calibration for long times. Another adjustment, not always fitted, is in series with the timer switch resistors, and adjusts the short times.

Digital timers

- These use a highly accurate crystal oscillator, which is divided down to provide timing clock pulses.
- The time selector switch loads a binary code into a digital counter. On start of the exposure, clock pulses subtract from the number in this counter. When the counter reaches zero content, the exposure time is finished.
- Although a digital timer does not require a time correction adjustment, there are adjustments for phase synchronization to the power mains supply. (Not required for a high-frequency generator.)
- Digital timers often have a separate analogue timer as a backup unit.
- **Note**. Some X-ray controls, although fitted with a digital display for selected time, may not have a digital timer, and instead use an analogue timer.

Microprocessor timers

- These are usually found with high frequency systems. There are no adjustments to calibrate the exposure time.
- The selected time is entered via a keypad, rather than a switch. The microprocessor downloads the required time to a separate backup timer, which is independent of the microprocessor timer once the exposure starts.
- On many systems, the microprocessor does not start the exposure countdown until the X-ray HT has reached 75–80% of its required value. This allows very accurate timing of exposures, down to 1.0 millisecond or less.

Milliamp second (mAs) timers

There are three versions of the mAs timer.

- **Microprocessor controlled mAs timer**
  Some X-ray controls have the option of selecting the exposure by kV, mA, and time. This is called 'three knob' technique. Or the operator may prefer to use a selection of just kV and mAs, called 'two knob' technique. Of this last method, the computer looks at the X-ray tube data stored in memory, and selects the optimum combination of mA and time selection to provide the shortest exposure. Of course, this does mean at times the X-ray tube may be working close to its maximum ratings. To avoid this, some controls have an added selection of ~80% load, instead of maximum tube load.
- **Digital mAs timer**
  The digital mAs timer directly operates from the mA produced during the exposure. By passing the generated mA through a resistor, a proportional voltage is produced. This voltage in turn controls a voltage to frequency (V/F) converter, which may produce ten pulses per mAs. When a required mAs is selected, this value is loaded into a counter. The pulses from the V/F converter subtract from this preset value, till the counter reaches zero. This ends the exposure. Digital mAs timers may also be supplied with microprocessor controlled high-frequency generators, for example, a mobile generator. Typically in this case the microprocessor also selects a suitable mA output to match the required kV and mAs.
- **Analogue mAs timers**
  With a CD mobile, mA generated during an exposure falls together with the kV. For this reason CD mobiles are fitted with mAs timers, of which the analogue version is the most common type.
  With an analogue mAs timer, the mA generated during an exposure produces a voltage across a reference resistor. This voltage in turn is used to charge a timing capacitor in the same fashion as a standard analogue timer. The important difference is that the voltage for timing control is now proportional to the mA generated during the exposure, and not a fixed voltage as in a standard timer.

e. *Automatic exposure control (AEC)*

Automatic exposure control or photo-timer is usually an option on purchase of an X-ray system. The AEC control is normally mounted inside the X-ray control cabinet. Older systems may instead have an external control unit.

In setting up for an exposure with AEC, the X-ray control timer is set for about 25% to 50% longer exposure time than expected. Some X-ray controls may not require a preset exposure time, instead using a principle called 'falling load'. Falling-load allows the generator to start at a high output, then as the exposure continues, lower the mA generated by reducing filament heating. This allows for extended exposure times, but still within the X-ray tube rating. Compensation is required, to keep kV at the correct level as mA drops.

In operation, the AEC measures the quantity of radiation entering the cassette. When this radiation reaches a predetermined level, an 'end of exposure' signal is sent to the X-ray control timer, terminating the exposure.

Ionization	Sometimes known as 'Iontomat' (Siemens) or 'Amplimat' (Philips). These depend on the minute current generated as gas molecules are ionized by X-ray radiation. Earlier types used atmospheric air as the medium. Later types may use a special gas, such as xenon, to improve sensitivity. Earlier ionization systems were sensitive to high humidity levels. Later systems have a pre-amplifier sealed into the same container incorporating the ion chambers. Adjusting the voltage gain of amplifiers, and the voltage reference for the exposure integrator, controls sensitivity.
Solid state	These depend on the detection material, which when energized by X-rays produces a small electric current. Adjusting the voltage gain of amplifiers, and the voltage reference for the exposure integrator controls sensitivity.
Photomultiplier	The detection area is formed by a thin pocket of luminescent material, similar to that used in a cassette, inside a sheet of translucent acrylic. Light is focussed from the edge of this acrylic into a photomultiplier. The output signal from the photomultiplier is very high compared to the other two methods, and is reasonably immune to humidity problems. The photomultipliers add to the total size of the system, so it can only be installed in a Bucky designed for a particular unit. Adjusting the voltage supply, and / or the last dynode voltage controls the photomultiplier sensitivity. Final adjustment to this type of AEC is otherwise similar to the other two systems.

Measurement of radiation for different sections of the anatomy is required. This is provided by measurement chambers in selected positions. These may be in the centre, or offset to either side for chest exposures. AEC exposure-controls allow for a selection of density, normally in +/– 5% steps, and may also incorporate sensitivity adjustment for different film/cassette combinations.

Provision is sometimes made to obtain an 'average' measurement by adding two or more chambers together prior to an exposure. In other systems, separate controls are incorporated for each chamber. By selecting two or more together, whichever chamber obtains most radiation controls the exposure.

To be successful, the chamber for measuring radiation should be placed between the X-ray grid and the cassette in the Bucky. This reduces sensitivity to scattered radiation. A kV correction signal is required, so the AEC can match the characteristic of the film-screen combination in use.

With conventional generators, especially single-phase versions, special contactor arrangements are required to avoid 'jitter' when approaching short times. This is due to SCR contactors not switching off immediately, but waiting for the next 'zero crossing' point. On a 50 HZ system this may cause a variable extension of up to ten milliseconds exposure time. (This problem does not exist with high-frequency systems.)

The film processor must also be accurately maintained, especially if the AEC is being calibrated or tested. There are three varieties of AEC systems for measuring radiation, ionization, solid-state, and photomultiplier systems. The differences are listed above.

f. Fluoroscopy timers

On older generators, small motors, similar to those used in electric clocks, have operated these timers. Later systems used a separate digital timer and display. With current systems, this function is integrated with the microprocessor control.

The timer only operates during a fluoroscopic exposure, and normally has a maximum time setting of five minutes. When the timer approaches the time limit, a warning buzzer may sound. At the end of five minutes, further exposures are prevented unless reset. (Some systems have a switch to bypass this requirement, depending on individual country regulations). Other facilities may be provided with digital fluoroscopy timers, such as total elapsed fluoroscopy time etc. This depends on individual features of a control system.

g. Exposure contactors

Exposure control on old systems was by mechanical contactors. (A contactor is a heavy-duty relay). These contactors require accurate adjustment to ensure the 'make' and 'break' of power to the high-tension generator occurs at the correct phase interval, otherwise severe arcing results.

When silicon controlled rectifiers (SCR) became available, these replaced the mechanical contactors for control of the actual exposure. Mechanical contactors are still required, however, in case of a faulty SCR, as these may develop a short circuit. This is called a 'backup contactor'.

An SCR has the property that once conducting, it remains conducting until the voltage across the device either falls to zero, or changes its polarity. A short positive pulse of voltage is applied to the SCR 'gate', relative to the cathode, to switch on the SCR. The SCR, as it is also a rectifier, will only conduct in one direction. To form a contactor two SCR units are connected in parallel, with one facing the opposite direction.

A basic SCR contactor system is shown in Fig E–29.

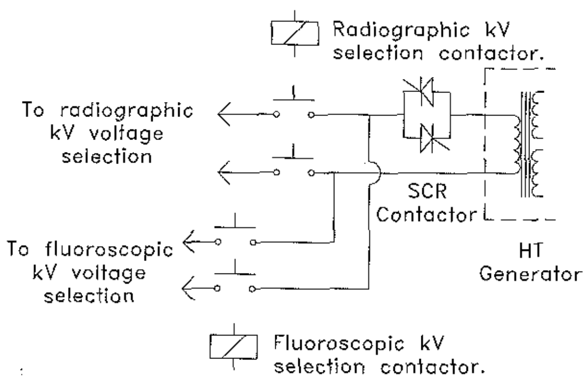


Fig E–29. A basic 'SCR' exposure contactor, for a single-phase generator

h. X-ray tube anode rotation

On preparation for an exposure, two main events happen. The anode is caused to rotate, and the X-ray tube filament is boosted to full operating temperature.

A time delay is required to ensure both anode rotation and filament boost has been completed before permitting an exposure. In many systems, the timer in the anode rotation control allows for both these requirements.

Anode rotation for low speed operation is controlled by the power mains frequency, either fifty or sixty Hertz. (50/60 Hz). **See Fig E–30.**

- On preparation request, relay R4 operates connecting 200V to the stator winding.
- A phase difference of ninety degrees between the current flowing in the 'start' and 'run' windings of the stator is required. This is supplied by the capacitor 'C'.
- **Note.** This capacitor requires a specific value to match the X-ray tube stator winding. If a different make of X-ray tube is installed, the value of 'C' may need to be changed.
- After the preparation time is completed, the control unit timer operates relay R3, which changes the supply voltage from 200V to 40V. This is to ensure the anode keeps rotating at full speed, but without the heat that would be generated if 200v were continuously applied.
- The two relays, R1 and R2, are current operated relays. These are for safety, in case either the start or run stator windings become disconnected, and prevent an exposure occurring on a stationary anode.
- Relay contacts R1, R2, and R3 form the preparation sequence safety system, and unless all are operated, an exposure is not permitted.
- Present day low speed starters have more elaborate fault detection, and may also have different preparation times, eg for over-table or for fluoroscopy.

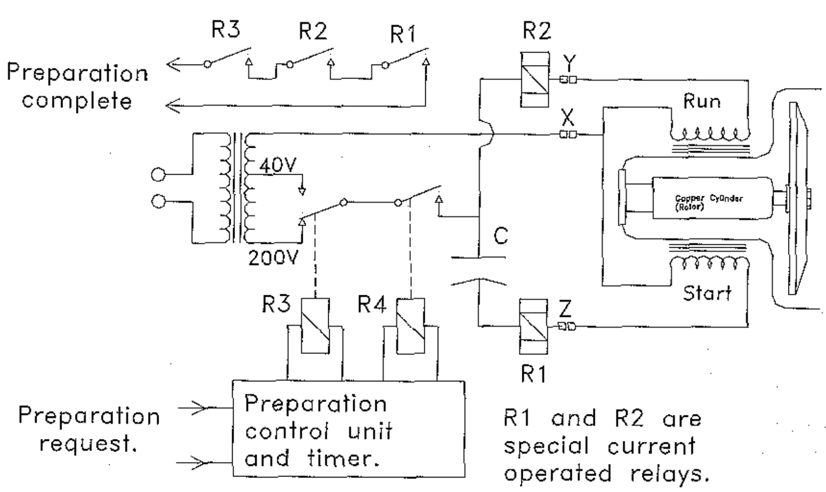


Fig E–30. A basic low-speed anode rotation control

High-speed rotation is provided by either a passive 'frequency tripler', or by an inverter system. The frequency tripler uses special transformers, connected to three-phase power. These transformers are driven in a saturated mode, and produce a highly distorted output, rich in harmonics. The output voltages are connected in series, so that the fundamental 50 or 60 Hz supply frequency is suppressed, and the third harmonic instead is selected. For a 50 Hz input, the output will now be 150 Hz. When applied to the X-ray tube stator, the anode will now rotate three times faster than at low speed.

With an inverter system, incoming single-phase power is converted to DC, and via the inverter back to AC. The inverter may operate at 150 or 180 Hz, depending on make or model. The majority however operate on 180 Hz, as this allows higher anode loads. For special applications, other drive frequencies may also be available.

An X-ray tube operated at high-speed will have greater stress on the bearings, and must not be allowed to coast down to a stop after an exposure. If this happens, there is a strong possibility of severe damage to the bearings, due to resonance affects at some anode speeds. To prevent this occurring, a high-speed starter provides a 'brake' cycle at the end of an exposure. This may be via a DC current through the stator windings, which quickly brings the anode to rest. A more common method is to apply a 50 Hz start signal, which brings the anode from high-speed quickly past the resonant positions to 3000 RPM. The anode then coasts to a stop.

High-speed operation, unless high power starters and special stators are used, may take twice as long to reach full speed. To overcome this problem, especially with a fluoroscopy table, two modes may be used.

- High-speed maintenance or 'hangover'. The starter remains in high-speed operation for up to 20 or 30 seconds from the last exposure.
- Low-speed maintenance or hangover in a fluoroscopy mode. This may last several minutes. As the anode is already rotating just below 3000 RPM, high-speed preparation time is reduced. In some starters, both techniques may be combined.

i. X-ray tube load calculation

An X-ray tube needs to operate within the maximum ratings for that tube, otherwise damage will occur. The manufacturer publishes rating charts, which specify the *maximum* operating conditions for the particular tube. **These parameters are:**

- The maximum rate of heat input for each focal spot, this is calculated from the product of kV and mA, and the exposure time. This will be modified by the speed of the anode, and if operated on single or three-phase. (Inverter systems are treated as three-phase)
- The maximum filament current of each focal spot, this limit occurs at low kV settings. This is required for filament protection.
- The maximum kV that may be applied.
- The maximum amount of heat stored in the anode, and the rate of anode cooling.

Note. These ratings are the *maximum* permitted. Regarding heat input to the anode, this is calculated for a cold anode, so it is unwise to make several exposures close together, **and** close to the maximum permitted input.

All X-ray controls have protection for anode heat input and kV limit. The other parameters depend on the level of design complexity. Present day microprocessor controlled systems may take all calculations into consideration, except tube housing temperature.

A typical rating chart is shown in Fig E–31. A number of load lines are provided for convenience. If we examine the 100 kV load line and compare this to 150 kV and 80 kV lines, we will find that the product of mA and kV is the same. See table E–5.

Table E–5. Maximum anode load at 0.1 second

100 kV and 660 mA	100 × 660 = 66 kW
150 kV and 440 mA	150 × 440 = 66 kW
80 kV and 825 mA	80 × 825 = 66 kW

By using the data shown in Fig E–31, we can obtain the maximum available output for a range of different conditions. These are shown in table E–6.

Table E–6. Maximum anode loads for the rating chart of Fig E-31

0.05 second	125 kV	560 mA
0.05 second	100 kV	700 mA
0.1 second	100 kV	660 mA
0.1 second	80 kV	825 mA
0.3 second	110 kV	500 mA
0.5 second	80 kV	600 mA

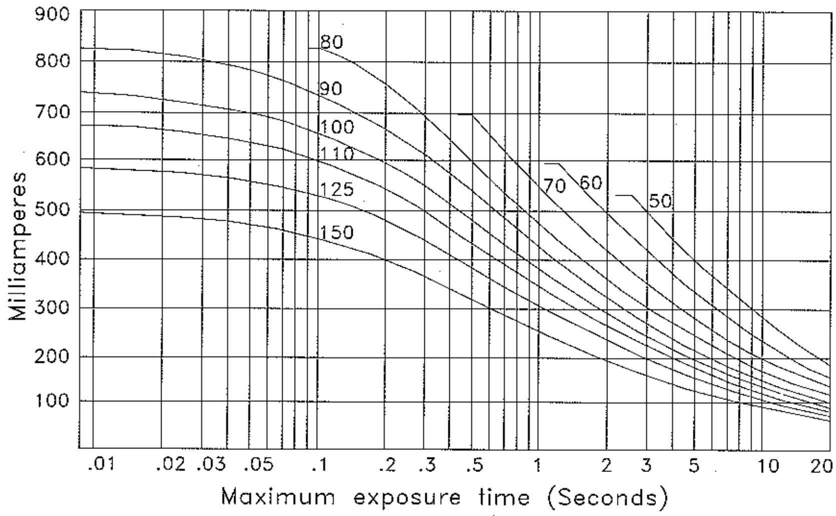


Fig E–31. A typical X-ray tube rating chart

The load lines for 50, 60, 70, and 80 kV stop after reaching a specified mA. This is because the filament will reach the maximum filament current, if required to produce that mA at the specified kV. For example, if at 60 kV an attempt was made to expose at 800 mA, 0.1 second. Although this is well within the anode load limit, the filament current would be excessive, and damage the filament.

In a microprocessor system, the computer carries out all the required calculations. Providing an X-ray tube from the same manufacturer is supplied, a code number is entered for the designated tube. In case the tube to be installed is not included in the list of codes, many controls allow input of full parameters derived from the rating charts, as a 'non standard' tube. With older X-ray controls it is necessary to adjust a series of potentiometers to obtain the correct calculation. These are normally adjusted at specified time positions, with separate adjustments for maximum kV and filament protection (if provided). Still other systems may use a patch-board, with wire jumpers connected between a series of selected pins, but with a similar goal in mind.

j. Operation sequence control

An X-ray control will perform a number of functions besides the actual X-ray exposure. These are concerned with ensuring the system is ready for use, preparation, exposure, fault detection etc.

A digital logic diagram for operation sequence control is shown in Fig. 32.

On power up

- X-ray tube selection in the HT transformer is activated.
- The X-ray tube filament pre-heating is commenced.
- Safety system tests for immediate faults.
- Microprocessor (if fitted) is initialized.
- With high-frequency systems, the inverter power supply capacitors are charged up.

Before radiographic preparation is permitted

- A valid technique selection is required. Hand switch operation should not be possible, if the fluoroscopy table has been selected. Some selections may not be available, eg, accidentally selecting tomography position, if not installed.
- Exposure factors must be within the X-ray tube capacity. (Maximum kV, anode load etc.)
- The X-ray tube housing over temperature switch should not be operated.
- For systems with servo (motor driven) mains voltage correction, or kV selection, preparation should wait till adjustment is finished. (But some designs omit this precaution.)
- On initial power up, or if a tube change is selected, a time delay may be inserted to allow preheating stabilization of the X-ray tube filament. This will also occur if tube change over is by a motor driven switch.
- No fault conditions should exist, eg, faults occurring from a previous exposure or preparation problem.
- In some countries, a door safety switch is required, to prevent exposures if the door is opened. This may also prevent preparation.

On commencement of radiographic preparation

- The preparation hand-switch is operated.
- Preparation request is sent to the tube starter, anode rotation commences.

- The preparation timers commence timing out.
- The X-ray tube filament is boosted to full preset temperature for the required mA.
- Tests are made to ensure no faults with anode rotation or X-ray tube filament.
- Warning light on the X-ray room entrance is illuminated.
- On conventional generators with SCR contactors, a backup safety-contactor connects radiographic power to the SCR contactor. A test is made to ensure there is no short circuit in the SCR contactor.
- Lockout any inputs for fluoroscopy request.
- Change over mA measuring circuits from fluoroscopy mA to radiographic mA.
- Servo-motors for line voltage compensation and kV selection are locked out to prevent operation.
- Peripheral equipment will also go into preparation mode. Eg, on remote controlled systems, the film will move into position.

On completion of preparation, to obtain 'ready for exposure'

- Preparation timer has 'timed out'.
- Anode rotation safety check is satisfied.
- No fault has occurred with filament heating.
- No system fault has occurred.
- Peripheral equipment is ready.
- 'Ready' signal appears on the control panel.

To obtain a radiographic exposure

- Preparation is completed. Exposure hand-switch is operated.
- Operate 'X-ray On' warning signal.
- Send an exposure request to peripheral equipment, eg, Bucky.
- Bucky operates, and returns the exposure signal to the X-ray control.
- On conventional equipment, the timer commences operation. The timer controls correct closing of the exposure contactor. (Mechanical or SCR version).
- On high-frequency systems, both timer and inverter commence operation.
- If fitted, a backup safety timer commences operation.

During a radiographic exposure

- Measure and display mA or mAs during exposure. (Only some systems).
- Measure mA, and operate mAs timer. (If fitted).
- Measure mA, and correct X-ray tube filament heating to ensure correct mA. (Only on some systems).
- Test for kV or mA faults.
- Test for system faults.

At the end of a radiographic exposure

- Send a time-up signal to peripheral equipment, such as a fluoroscopy table.
- Test to ensure high voltage generation stopped. (In case of SCR contactor fault).
- Send a time-up signal to a double-exposure protection circuit. Preparation must be released and started again before another exposure is made. (Not on all systems).

At the end of preparation, following a radiographic exposure

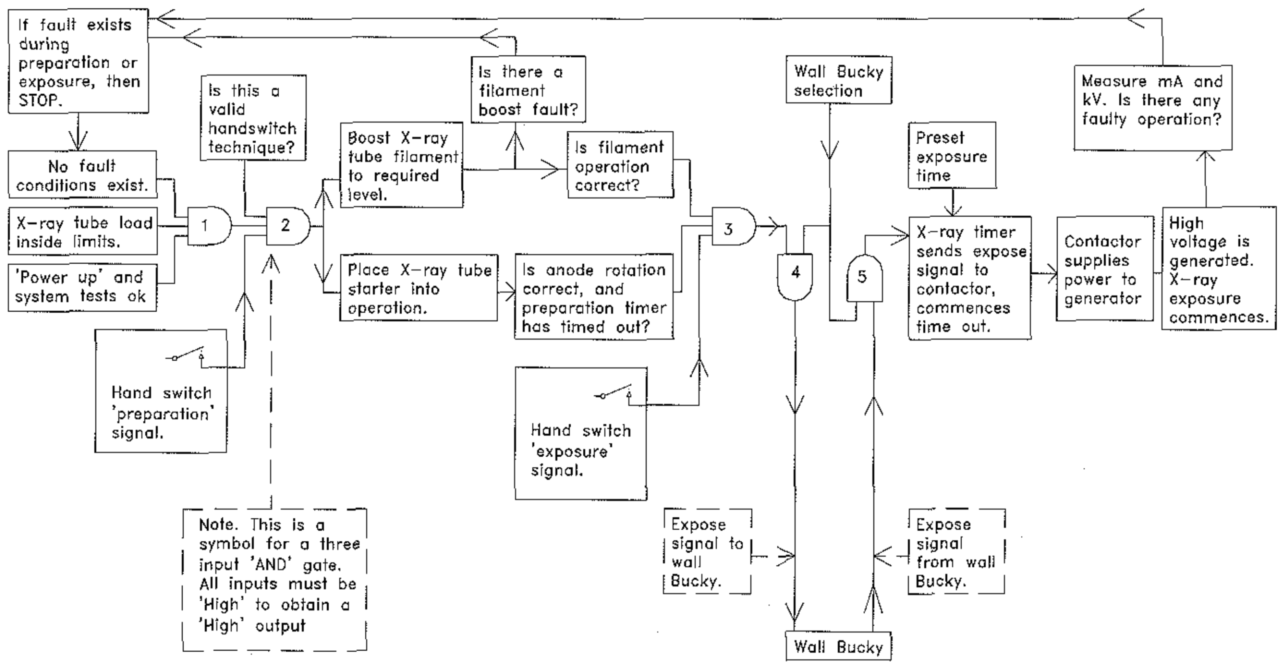
- Filament heating is returned to standby preheating.
- A one second 'filament-cooling' timer commences operation. This is required in case the next exposure is for fluoroscopy. For example, if a 500 mA radiograph exposure has just been made, the filament must cool down before allowing a 2.0 mA fluoroscopy exposure.
- Return mA measuring circuits from radiographic mA to fluoroscopic mA.
- If anode rotation was high-speed, the starter now generates a brake cycle.

To obtain a fluoroscopy exposure

- The fluoroscopy timer has not reached the time limit. (Usually five minutes.)
- The X-ray tube filament is not in a cool-down cycle. (After a radiographic exposure).
- The fluoroscopy table safety interlocks are satisfied.
- The room entry door is closed. (Required in some countries).
- A valid technique and X-ray tube has been selected.
- Power to the generator is now selected from the fluoroscopic kV control section.
- In three phase systems, fluoroscopy is most often performed in single-phase mode. The capacitance of the high-tension cables provides the required smoothing of the kV waveform, so very little kV ripple occurs.
- With high-frequency systems, the inverter may select a different mode of operation than for radiography kV. This depends on system design.

During a fluoroscopy exposure

- Operate 'X-ray On' warning light at the entrance door.
- The generated fluoroscopic mA is displayed. (Most systems).



This diagram is to illustrate the basic sequence on making an X-ray exposure. In this instance, the wall Bucky has been selected prior to preparation.

As an illustration of fault detection, initially no fault will exist. However if a fault is produced, either during preparation or on actual exposure, then fault detection breaks the first AND gate, removing preparation and exposure signals. At the same time, the "OVERLOAD" or "FAULT" light will illuminate to indicate a problem.

Fig E–32. Operation sequence control

- Fault detection is set for fluoroscopy conditions.
- The fluoroscopic timer is activated.
- A warning audible signal during fluoroscopy may be generated. (Required in some countries, especially if in 'boost fluoroscopy' mode).
- X-ray 'on' signal is sent to the TV system. Digital TV systems with a 'last image hold' feature will now display images in 'real time.' These images will also cycle through a digital memory.

At the end of a fluoroscopic exposure

- With digital TV systems, the TV memory retains the picture obtained just before the exposure finished, and displays that image as 'last image hold'.

k. Fault detection and safety systems

The X-ray control has many systems for detecting faults in operation, and provide for safe operation. Safety systems are provided to ensure correct sequence of operation. These take the form of 'interlocks', which mean that a predetermined series of events must be satisfied before proceeding. Many such interlocks are provided to avoid operator error. For example:

- X-ray tube load protection.
- Selection of an incorrect technique.
- Include which X-ray tube in the technique selection.
- Not permitting exposures that exceed country regulations.
- Exposure time selected is too short for the selected mA. (Some microprocessor systems do not permit exposures less than 0.5 mAs).

Interlocks also ensure that if a fault is detected, further operation is disabled. This may even extend to switching off the complete system.

As X-ray control design has become more complex, there has been an increase of provisions for detecting possible faults, or wrong operation. Later systems often display a code on the front panel, to indicate the type of problem. In many cases the meaning of this code will be found in the operator or installation manuals.

Some models allow clearing of 'non fatal' faults by pressing the 'power on' button. For example, the X-ray tube might have been unstable, and caused the previous exposure to terminate. By pressing the power-on button, another exposure can be attempted. (It is advisable to reduce the exposure settings first, before making a test exposure.). In the case of 'fatal' faults, these will prevent operation unless the control is switched 'off' then 'on' again. In such a case, considerable caution is required, and any warning signals or codes should be investigated first.

While recent systems may display a fault code, or message, older controls may indicate a fault symbol, or just light up the same indicator used for X-ray tube overload. However, inside the control there are often many indicator LED indicators provided to indicate sequence operation or fault indication. Table E–7 indicates some of the safety interlocks and fault detection requirements that may exist.

Table E–7. Typical safety interlocks and fault detection requirements

On power up and system check.	Interlock test for operation of X-ray tube high-tension selection switch and stator connection relays. Has X-ray tube housing over temperature switch operated? On inverter systems, have the bank of inverter power supply capacitors charged up to the correct voltage?
Before preparation is permitted.	Has a valid technique been selected? Are the exposure factors within the safe operating area of both the X-ray tube and the generator? Entrance door safety switch not activated.
During preparation.	Is the current through the X-ray tube filament transformer above a minimum level? (If below, can indicate open filament connection). Is the filament current inside the maximum limit? Is the current flowing in both the 'start' and 'run' stator windings of the X-ray tube the correct value? Look for illegal voltage on generator transformer primary winding. (In case of an SCR contactor fault in conventional systems). Energize a warning light. 'Do not enter'.
At end of preparation.	Interlock for preparation timers. (Older systems may depend only on the stator control; later systems include a timer for minimum filament heating time.)
On exposure request with peripheral equipment, eg Bucky.	Hand switch exposure request is sent to the required Bucky. The Bucky must move the grid and trigger an interlock to indicate the Bucky is ready for an exposure. This interlock relays the exposure request back to the X-ray control.
To commence actual exposure.	On conventional systems, the expose signal places the timer into operation. The timer waits for a synchronization pulse derived from the mains supply voltage, and at the correct phase interval operates the SCR contactor. With a mechanical contactor, the time for the contactor to operate requires a compensation adjustment. With an inverter system, the signal to the timer and the inverter may occur at the same time. Mains voltage synchronization is not required.
During exposure.	The mA is measured. If mA is higher than a preset detection limit, stop the exposure. With high-frequency systems, if kV is excessive, or, after a short measurement time too low, stop the exposure. Some inverter systems measure the transformer primary current, and if too high stop the exposure.
At the end of a radiographic exposure.	A time-up signal may be sent to peripheral equipment. If in high-speed mode, the X-ray tube starter will now produce a brake cycle. A filament cool-down timer will operate, so a fluoroscopic exposure cannot be made until this timer has finished.

PART 5 THE HIGH-TENSION CABLE

The high-tension cable used in X-ray generators has three main requirements.

- It must be able to withstand more than 75 kV, plus a safety margin. A typical value is 100 kVp.
- The cable requires good flexibility.
- In case of a fault or damage, not to cause danger of electric shock.

With the exception of mammography and some dental units, X-ray generators operate with balanced +/– high-tension above ground. When used with a 150 kV generator, each cable must be able to withstand a minimum of 75 kV.

To provide electrical safety, a woven mesh shield is placed on the outside of the bulk insulation, underneath the protective surface cover. This shield is connected to ground potential at both the X-ray tube and the high-tension transformer. Should a spark occur due to insulation failure, the shield conducts the discharge safely to ground. The cable capacitance plays an important part for high-frequency generators. Typical capacitance for a ten meter length is ~1800 pF.

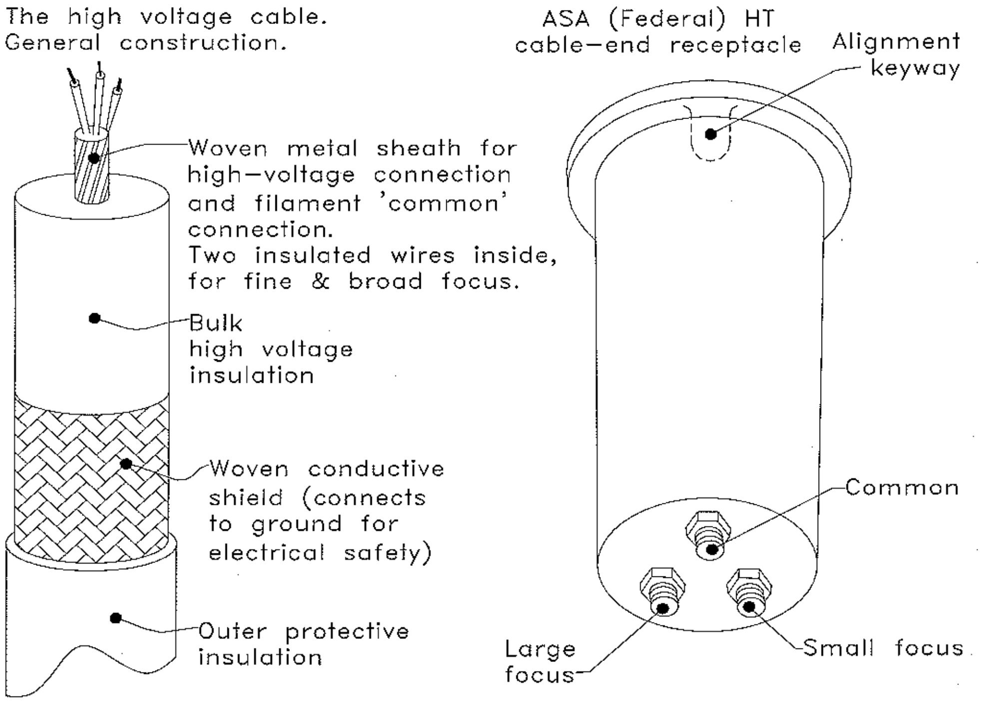


Fig E–33. The high voltage cable and standard ASA cable end receptacle

PART 6 THE X-RAY COLLIMATOR

An X-ray collimator is a device to limit radiation from the X-ray tube. A light beam is incorporated, to illuminate the patient area to be radiated.

There are several forms of collimators.

- 'Single leaf' versions, often fitted to smaller mobiles or portable generators. These are sometimes referred to as 'X-ray shutters'. The design requirement is small weight and size. The limitation is a blurred edge of the X-ray image on the film.
- 'Multiple leaf' collimators, incorporating at least two leaves or diaphragms, and in most cases, an additional small leaf positioned close to the X-ray tube focal spot. (This is to suppress off-focal radiation from the X-ray tube anode.)
- Automatic collimators. These may be either manually controlled as a standard collimator, or by remote control only, as in a fluoroscopy table. With an automatic collimator, the operator may reduce the size of the beam relative to the film area to be exposed, but cannot not exceed this area. These systems are sometimes fitted with a key switch to disable automatic collimation for special applications.
- Collimators for capacitor-discharge mobiles have an extra lead shutter to block unwanted radiation. This radiation occurs as dark-current when the capacitor is charged, or if the kV is reset to a lower value. The shutter may be motor operated and opened during preparation, or solenoid activated just prior to an exposure.
- Specialized collimators used in surgical X-ray TV systems, or angiographic equipment. These collimators often have an additional 'iris' diaphragm to limit the X-ray beam to the circular input of an image intensifier. They may also have additional rotating leaves fitted with a custom filter to reduce 'halation' due to a direct X-ray beam entering part of the image.

A sketch is provided in Fig E–34 of a standard collimator. This indicates the alignment of the light beam to the radiation field, and the lead diaphragms or leaves.

Referring to the sketch Fig E–34:

- Electrons bouncing off the focal spot, and re-landing on other areas of the anode cause off-focal radiation. This may amount to as much as 15% of the total radiation, but at reduced energy levels. The lead diaphragm 'a' reduces this off-focal radiation from the X-ray tube anode by applying a small aperture, very close to the focal spot. Some collimators have these leaves extended above the top of the collimator body, and fit inside the collimator-mounting device.
- A mirror set at an angle of 45 degrees is mounted close to the input of the collimator. The light bulb filament is positioned the same distance from the mirror centre as the X-ray focal spot. This ensures the light beam covers the same area as the X-ray beam.
- The diaphragms 'b' and 'c' limit the actual X-ray beam. The diaphragm 'c' cleans-up the 'penumbra' that would exist at the edge of the X-ray beam. (Penumbra is caused by the focal spot size not being a true 'point' source. Eg, the larger the focal spot, the greater the penumbra.)
- Moving the mounting position of the collimator, relative to the focal spot, allows adjustment of the collimator to the X-ray source. This is often provided by four adjustment 'fingers'. With rotating collimators, the holes for the mounting screws may be enlarged, allowing several millimetres of adjustment relative to the focal spot.
- The mirror and front Perspex cover provide some of the required primary beam filtration. Additional filtration to reach the required minimum total 'half-value layer' is often placed in the X-ray tube housing throat, just before the off-focal leaves 'a'. In other collimators the added filtration may

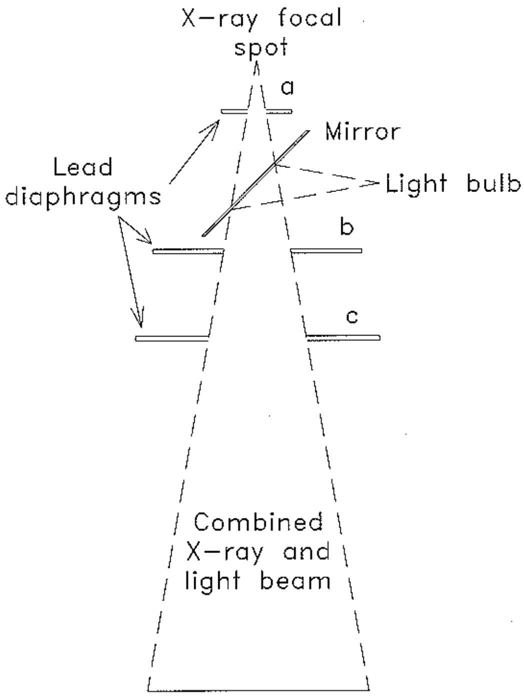


Fig E–34. Construction of the X-ray collimator

be removable. In these cases there is often an interlock switch, to prevent operation above a specified kV.

- A scale is provided for adjusting the field size to different cassette/film sizes. This may be for the standard one-meter distance from the film, or the equivalent inch distance.

Automatic collimation

Automatic collimation is a requirement for any fluoroscopic table fitted with an image intensifier.

Automatic collimation for over-table operation is now a standard requirement for some countries with strict radiation health regulations, and is often an optional requirement in other areas.

Basic description of operation (See Fig E–35)

- The collimator is fitted with motors to operate the diaphragms. Position of these diaphragms is measured by a potentiometer, with an output voltage relative to position.
- The collimator control produces a reference voltage equivalent to the required opening. This voltage is modified depending on the film to focus distance (FFD).
- The difference between the voltage from the collimator, and the control reference voltage, is amplified and operates the motor. The motor will move the associated diaphragms in or out, until the collimator voltage matches the reference voltage.
- When automatic collimation is applied to over-table or wall-Bucky operation, the tube stand is fitted with potentiometers to measure the FFD in both the vertical direction and the horizontal direction.
- With microprocessor systems, the voltage from the collimator and height measurement potentiometers is transferred, via an analogue to digital converter, to the computer. Film and format size is entered directly to the computer. The computer then outputs a control voltage, via a digital to analogue converter, for the motor drive power circuit.
- The vertical direction only is required for over-table operation. With a wall Bucky, the horizontal measurement is used for the FFD compensation, while the vertical measurement is compared to a similar height measurement from the Bucky stand. This ensures the X-ray tube is at the correct height to match the wall Bucky. In some cases, the X-ray tube stand height is motor driven to automatically track the wall Bucky height. In other cases, the tube stand height is manually controlled until a 'ready' indicator operates.
- Elevating Bucky tables may also send a height signal to the automatic collimator control, to permit operation at different positions. Other ele-

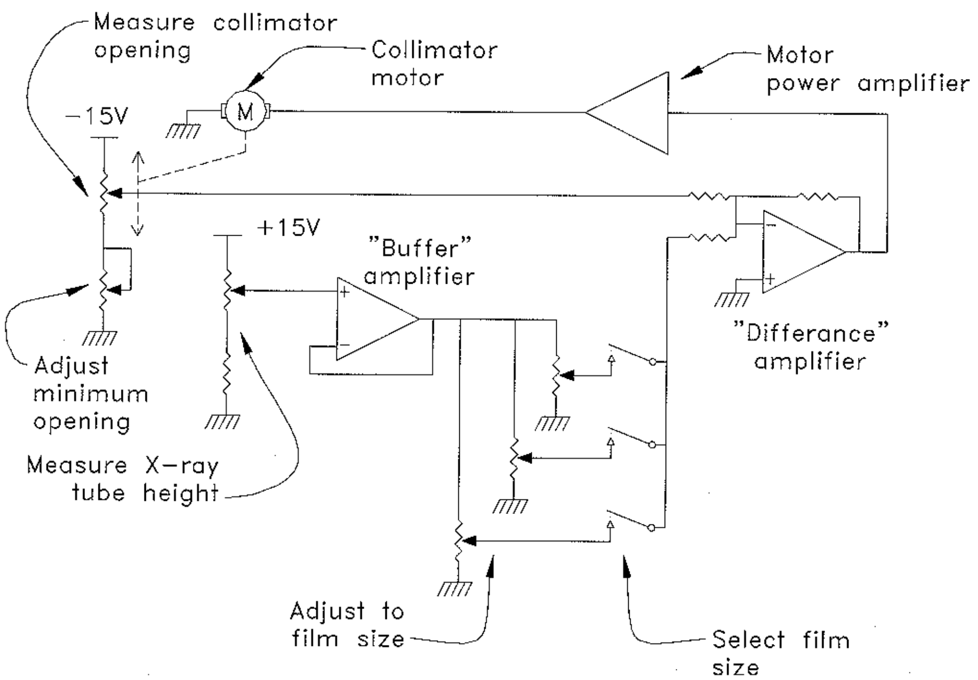


Fig E–35. Operation of an automatic collimator control system

vating tables may only permit operation when raised to a standard operating height.

- The Bucky used for these systems requires a method to determine the cassette size. This may be via potentiometers attached to the cassette tray. Some Bucky's provide a motor driven cassette tray, which passes over sensors as the cassette tray is retracted. These sensors are connected to a computer in the Bucky, which decodes the cassette size, and transmits the information to the collimator control unit.
- In the case of a fluoroscopic table, measurement of the cassette size may be via a combination of magnetically operated 'reed' switches, as the cassette is loaded into position. Many other systems also apply, including manual selection of cassette size via a selection control on the serial changer (spot filmer).
- A fluoroscopic table also selects different format sizes, to allow multiple exposures on the same film. To prevent overlap of exposures, an additional 'close to film' shutter is provided in the serial changer. These have a preset size according to the format selected, and provide a sharp delineation of the exposed film areas.

PART 7 THE X-RAY TUBE SUSPENSION

The X-ray tube stand is presented in two common forms, floor to ceiling, and ceiling mounted suspension. The ceiling mounted suspension allows maximum flexibility for a room, while the more economical floor-ceiling system is used for most general-purpose rooms. Ceiling suspended systems counterbalance the weight of the suspended X-ray tube by means of a spring and variable ratio pulley. Floor-ceiling stands may also use a similar system, or else have a counterweight installed inside the stand column. Adding or subtracting trim weights achieves adjustment of the balance point. In some cases adjustment of spring tension is also required.

To maintain the X-ray tube in the required position, manual or electrically operated locks are employed. The electrically operated locks will take the form of:

- Electromagnet. This requires power to activate the lock.
- Permanent magnet. This is an electromagnet with a permanent magnet instead of an iron core. When energized, the magnetic field generated by the electromagnet, cancels out the magnetic field of the permanent magnet.
- Solenoid operation. In this system, a spring-loaded brake pad forms the lock. On operation of the solenoid, the pad is pulled away from the brake surface.
- Rotary 'tooth' lock. The lock is fitted with two matching plates, fitted with fine 'teeth'. These are pressed together with a firm spring. On energizing an electromagnet, the spring-loaded plate is pulled away from the fixed plate, and permits rotation.

The tube-support provides indication when the tube is rotated around preset angles, commonly set at ninety-degree positions. The lateral movement will also have an indication when the X-ray tube is at the Bucky centre position. These indications may be provided by a spring-loaded ball fitting into a slot, or else by a cam operated micro-switch, or optical-sensor, operating the appropriate lock. In this case an indicator lamp is usually provided. An automatic stop at a standard height from the table Bucky, or distance from a wall Bucky, is often provided.

The height of the X-ray tube from the Bucky and the tabletop may be indicated by a set of fixed scales. In many systems height indication is provided by a digital display, operated by a potentiometer. Two potentiometers are required, one for the vertical movement, and one for the longitudinal position from the wall Bucky. Change over to the required potentiometer is performed by rotation of the X-ray tube. This system is also required if the X-ray tube is fitted with automatic collimation.

When the tube-support is used in tomographic mode, the following is required.

- Height above the table Bucky set to the required position. Some tube-supports have an interlock. This prevents operation if the height is not correct.
- The tube rotation lock released.
- The longitudinal lock or brake released.
- The height and lateral movement locks energized.

The above may be applied automatically, depending on make and model of the tube-support. In other cases, take care to ensure the locks are set correctly before operation.

PART 8 THE X-RAY GRID AND POTTER BUCKY

Contents

a. Compton, or scattered radiation
b. The Bucky grid
c. X-ray grid specifications
d. The Potter Bucky
e. Bucky systems for automatic collimation

a. Compton, or scattered radiation

When X-rays pass through atoms of any material, scattered radiation may be produced. This depends on the X-ray photon dislodging an electron. At the same time the original photon changes its direction of travel. The photon loses energy equivalent to the dislodged electron, and has a longer wavelength. This is called 'Compton' radiation.

Scattered radiation will exist even with an X-ray beam passing through air, but especially when passing objects such as a patient. For this reason radiation shields and protective clothing are required. Scattered radiation also causes fogging of the X-ray film, reducing detail and contrast. This is illustrated in Fig E–37.

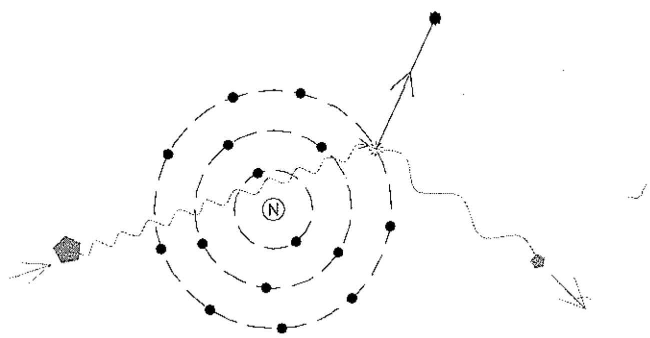


Fig E–36. Compton, or scattered, radiation

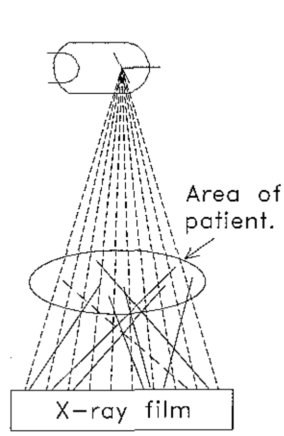


Fig E–37. Scattered radiation causes film 'fogging'

b. The Bucky grid

Dr Bucky invented the X-ray grid in 1913; from this we have the name 'Bucky grid'. The grid is used to reduce the effects caused by scattered radiation. Thin strips of lead, spaced by material having a low X-ray attenuation, form the grid. This material may be wood or aluminium, and in high performance grids, carbon fibre.

While many specialized grids have been developed, the 'focussed grid' is most commonly used. This grid has the lead strips angled slightly to accept the X-ray beam from the X-ray tube, positioned at a specified distance. Although the X-ray beam is able to pass through the grid interspace material, X-rays from other directions are blocked by the lead strips, and do not enter the film.

A focussed grid is illustrated in Fig E–38, and grid action in Fig E–39.

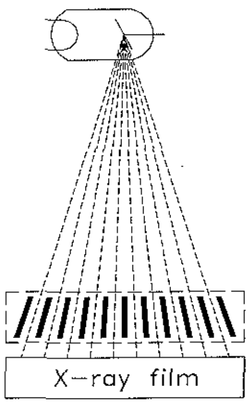


Fig E–38. The focussed grid

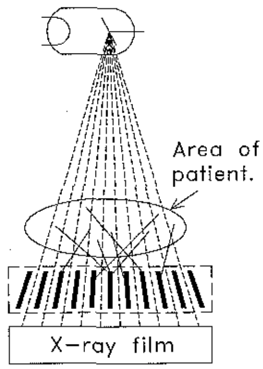


Fig E–39. The grid absorbs scattered radiation

c. X-ray grid specifications

- Grid ratio. This is the ratio of the height of the lead strips (H), and the distance between them (D). R = H/D, and is expressed as a ratio, for example, 8:1.
- Lines per inch or lines per centimetre
- Focus distance
- Interspace material
- (See Fig E–40)

As grid ratio is increased, so is a greater absorption of the useful X-ray beam. This absorption is called 'Bucky factor', and depends also on the interspace material and the number of grid lines. An increase in Bucky-factor requires an increase in X-ray output together with increased radiation to the patient.

An increase in grid ratio results in improved rejection of scatter, together with an improvement in contrast. However, the centring of the grid to the X-ray beam becomes more critical, and focal range becomes smaller.

Table E–8. Typical specifications for X-ray grids

Lines per cm	Ratios	Focal distances
60 Lines/cm (24 Lines/inch)	8:1, 10:1, 12:1, 14:1, 16:1.	65, 70, 80, 90, 100, 120, 150, 180, 200 cm
40 Lines/cm (16 Lines/inch)	6:1, 8:1, 10:1, 12:1, 14:1, 16:1.	As above.
34 Lines/cm (14 Lines/inch)	5:1, 6:1, 8:1, 10:1, 12:1.	As above.

Table E–9. Common grid applications

Wall Bucky. Chest	12:1 ratio, 40–60 lines/cm, 150 cm focus.
Wall Bucky. Spine, Abdominal etc	10:1 ratio, 40–60 lines/cm, 100–120 cm focus.
Table Bucky	10:1 ratio. (8:1, 10:1, 12:1) 100 cm focus.

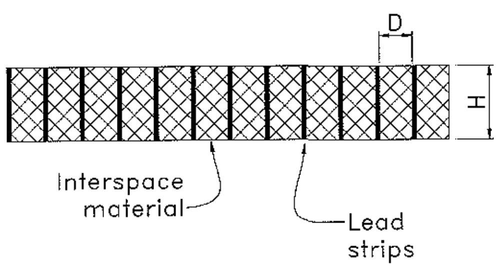


Fig E–40. Formation of an X-ray grid

d. The Potter Bucky

When a fixed grid is used, the lead strips in the grid cause a series of white lines on the film. This is where the lead strips have blocked the radiation from the X-ray tube. By moving the grid during the exposure, these lines are blurred out, and fine detail that may have been covered becomes visible. In action, the grid only travels a few centimetres in or out around the centre position.

Dr Potter invented the moving grid in 1920. This was originally called a Potter-Bucky Grid. Nowadays the device for moving the grid is commonly just called a Bucky.

There are two modes of operation for the Bucky.

- Random oscillation. The grid stars reciprocating (moving in and out) immediately the X-ray control prepares for an exposure. This method can have random appearance of grid lines, especially with short exposures. This is caused if the exposure occurs just as the grid reverses its direction of travel.
- Synchronized oscillation. The grid starts to move only after preparation and when the X-ray exposure button is pressed. After the grid has moved a short distance, a relay or switch closes, and returns the exposure request back to the X-ray control. This method ensures an exposure does not commence, while the grid is just starting to reverse its direction of travel.

The method of moving the grid varies greatly depending on design requirements.

- Linear movement provided by a reversing motor drive. Some manufactures may provide a selection of speeds. Eg, 'Par speed' or 'Super speed' as an example.
- Variable speed provided by a motor driven cam. This allows the grid to move quickly during the early part of an exposure, slowing down as the exposure progresses.
- 'Sine-wave oscillation' by solenoid activation. The grid is supported on four steel strips acting as springs. On preparation the grid is pulled to one side by the solenoid. On exposure the grid is released, and oscillates in and out until it comes to rest.

The speed at which the grid travels can sometimes cause grid lines to appear. With a single-phase generator, if the grid speed is a division of the mains frequency, the grid lines will overlap on succeeding pulses of X-ray output. Grid lines may also appear if the grid is slow, and a fast exposure is used. Some Bucky's provide rapid oscillation to overcome these problems. Unfortunately, in some cases this may cause the whole assembly to shake, producing a blurred film.

A mammography Potter-Bucky is often provided with a speed control. The speed is adjusted so the grid, during an average exposure, reaches about three quarters of the maximum travel distance. Eg, if the grid were to oscillate, grid lines are produced at the point when the grid reverses travel direction.

e. Bucky systems for automatic collimation

In some systems, automatic adjustment of the X-ray beam is provided by measurement of the cassette size. This prevents unnecessary radiation to the patient caused by incorrect adjustment of the X-ray collimator field size.

- One method measures the cassette size by two potentiometers, X and Y. These are provided in the Bucky cassette tray. On inserting the tray a plug and socket connects the potentiometers to the auto collimator system.
- Another method is provided by a microprocessor controlled Bucky. This uses a motor to drive a cassette tray in and out of the system. On inserting a cassette, the tray is pulled back inside, passing a sensor. By counting the number of motor 'steps' for the front of the cassette to reach the input sensor, the computer calculates the cassette length. The side arms gripping the cassette operate other sensors to provide the width. With the cassette in position, the microprocessor then sends the required information to the auto collimation control. These systems are required to be preset for either inch or metric cassettes.

PART 9 TOMOGRAPHY

Tomography is a technique that allows specific areas of the body to be visualized. By 'blurring out' unwanted organ outlines, the outline of organs at a specified depth are made visible. This technique may also be known as planigraphy, stratigraphy, or laminography.

When several areas of the body are superimposed on top of each other, it is difficult to visualize the organ under examination. To help with diagnosis, angled views are commonly used, as illustrated in Fig E–41.

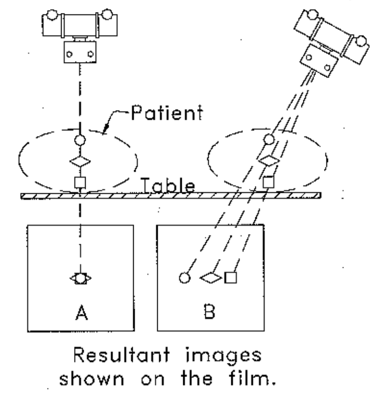


Fig E–41. Angulation provides more information

When there are a large number of similar anatomical areas, the merged outlines make diagnosis difficult. If however, the X-ray tube and film are moved simultaneously around a common axis during the exposure, the outlines of unwanted areas are blurred out. This is illustrated in Fig E–42.

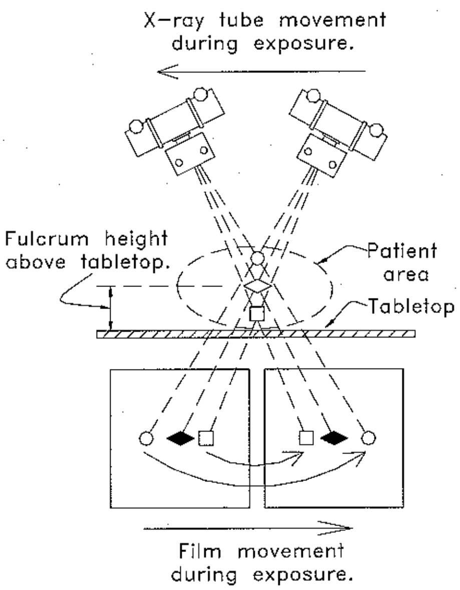


Fig E–42. Tomographic movement blurs out unwanted outlines

The common axis of rotation, or fulcrum, determines the height at which the required section will remain in 'focus'. This is called the 'focal plane'. As the angle of rotation is increased, the area or 'body section' that is in 'focus' becomes thinner. For this reason, tomographic systems allow the selection of several angles to suit the required examination.

There have been many complex systems developed to improve blurring of unwanted areas. Of these, the linear movement is commonly employed, especially as the equipment involved can be added to a standard Bucky table.

Linear tomography requires:

- A motor to move the tube stand. The motor may have several selectable speeds.
- A coupling bar between the X-ray tube and the Bucky. This bar will pass through a fulcrum, so the tube stand movement will produce an opposite movement to the Bucky. The coupling bar also aligns the X-ray beam to the Bucky.
- A system of sequence switches. These determine the start point of tube stand movement, the start and finish of X-ray exposure, and the stop position of the tube stand. These switches are often located in the fulcrum mechanism, and may be operated by a cam. In other systems, they may be included in the motor drive, and directly measure the distance of tube-stand travel.
- A method of changing the fulcrum height, relative to the tabletop. In most systems this is by directly changing the fulcrum height. Some tables (such as a remote controlled fluoroscopy table) may instead use a fixed fulcrum height, and raise or lower the tabletop.

A tomographic system may also be provided with several operation and safety interlocks:

- Tube-stand height. If not correct, no operation. (Some systems)
- Tube-stand locks. Rotation and longitudinal locks should be 'off'. Vertical and lateral locks should be 'on'. Most systems have a relay to provide this function on selection of tomography.
- Coupling bar inserted. Safety interlock is required if the fulcrum has switches controlling the tube stand motor. Earlier designs may not have this feature.
- Bucky lock 'off'. Again this depends on system design. If the Bucky has a mechanical lock, it is important the operator ensures this **is** off before operation.
- Operation of the Bucky grid movement. This may occur as soon as the tube stand starts to move, and finish either at the end of the tube-stand movement, or when the exposure handswitch is released.
- A typical timing chart is provided in Fig E–43.

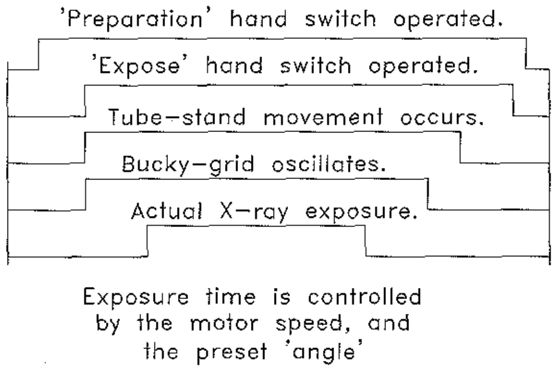


Fig E–43. Timing chart for a tomographic exposure

The exposure time is controlled by the tomography system. In use, the X-ray control timer is set to a longer time than required. This ensures the tomography system will terminate the exposure, and not the X-ray control timer.

'Electronic' tomography

- This is a system in which the mechanical fulcrum or pivot point is dispensed with. Instead three motors are required, one to move the tube stand, one to align the X-ray tube, and one to move the Bucky the required distance in the opposite direction.
- Some remote controlled tables using this system may still have a coupling bar permanently positioned. This however is required solely to keep the X-ray tube aligned to the Bucky (or serial changer).
- In operation, a potentiometer measures the relative distance of the tube stand, and another potentiometer the distance of the Bucky. (Or serial changer in the case of a fluoroscopic table). The speeds of the two motors are tightly controlled by means of a tachometer (or 'convolver') attached to the motor shaft. The information from the potentiometers and tachometers are fed via a computer to the motor drive systems.
- The advantage of the above system is convenience, and in many cases, a faster tomographic scan time. Mechanical problems due to coupling and uncoupling mechanical sections are eliminated. The disadvantage is cost and electronic complexity.

PART 10 THE FLUOROSCOPY TABLE

Contents

a. Fluoroscopy table description
b. Serial changer features
c. Table operation
d. Safety interlocks

a. Fluoroscopy table description

The fluoroscopy table is designed to allow direct viewing of the patient using continuous X-ray radiation.

Earlier tables used a fluorescent screen for this purpose. The operator is protected from direct radiation by a layer of lead glass on top of the fluorescent screen. As the image produced has a very low light level, this requires special viewing conditions. Present systems use an Image Intensifier or 'II'. This is coupled to a TV camera and monitor, and permits viewing under normal room illumination.

A serial 'changer' (or spot filmer) is used to obtain multiple radiographic exposures on a single film. The serial changer contains most of the operating controls for the table, as well as the fluorescent screen, or image intensifier.

There are two main forms of fluoroscopy tables

- Undertable X-ray tube. This is most common. The serial changer, sometimes known as a spot filmer, is mounted on top of the table. The table controls require manual operation, with the radiologist beside the patient. Due to the tube being mounted under the table, space is limited, and the distance of the focal spot to the patient is relatively short. The serial changer on these tables can be retracted, to allow full use of an undertable Bucky.
- Over-table X-ray tube. This format is normally fitted to a remote controlled table. Some versions allow for an additional control desk mounted on a trolley, for tableside operation. With the X-ray tube positioned above the tabletop, a much larger FFD is obtained. Tomographic operation is usually included, with the serial changer taking the place of a Bucky.

The table is able to tilt from horizontal to ninety degrees vertical, with the foot end towards the floor. Another tilt direction, called 'Trendelenburg' allows the head end to tilt towards the floor. Some tables may only allow about fifteen degrees of tilt in this direction. Other versions, depending on design, may allow thirty degrees, or else full ninety degrees. These are termed 90/15, 90/30, and 90/90 respectively.

Tabletop movements will normally allow for longitudinal movement beyond the head or foot end of the table body. This movement will either retract, as the table tilts to avoid collision with the floor, or else the table tilt will halt until the operator repositions the tabletop.

Note. Some over table remote control tables have no longitudinal tabletop travel. Instead the mechanism allows the undertable serial changer to travel for the full length of the tabletop. Lateral tabletop movement is available on all except the more basic tables. This movement usually has an auto stop when centred.

b. Serial changer features

- Direct fluoroscopy viewing via an image intensifier and TV combination. In this mode the film cassette is positioned to one side, together with lead shielding to protect it from scatter radiation.
- The cassette carriage is able to move the cassette in both the vertical and horizontal plane. This allows for a number of exposures to be taken on the same film. (Hence the alternate name of spot-filmer).
- Two motors usually perform movement of the carriage, with a variety of different methods to determine the stopping position. On simpler tables, movement is performed manually, with the position controlled by an electromagnet, or solenoid operated, mechanical 'stop'.
- A serial changer may accept a number of different film sizes and formats. On most serial changers, the cassette size is measured automatically as it moves into the serial changer. On older systems, the size may have to be entered manually. The formats available depend on the serial changer design and film size.
- Automatic collimation is required to limit the beam to the image intensifier field size, or to the film format size, whichever is the smallest area.
- As the collimator does not have precise registration of the X-ray beam to the film, this would result in overlap of exposures when a multiple format is selected. To prevent this, an adjustable lead 'mask' is positioned in the X-ray entrance area. The mask has a preset size to suit the format required. This allows the film to be divided into two or three vertical strips, or 'splits'.
- A second mask, sometimes attached to a compression cone, is placed in position when a 'four spot' film format is required.
- When making multiple exposures on one film, an exposure counter is required. On completion of the exposures for that film, no more exposures are permitted. Depending on the table design, the cassette may also be automatically ejected, ready for the next cassette to be inserted.
- The serial changer will have an X-ray grid fitted. In simple tables, this may be a fixed grid. When an oscillating grid movement is fitted, the X-ray exposure is normally synchronized to the grid movement. Again, a variety of methods are used for the grid movement, and in some tables the grid can be retracted to allow for non-grid exposures.

c. Table operation

On a preparation and exposure request from the table, the following takes place:

- The fluoroscopy signal from the table is locked out.
- The locks for serial changer movement, over the patient, are energized.
- Tabletop movement controls are disabled.
- The auto-collimator changes its format from the image intensifier field size, to that of the film in the cassette.
- The film cassette moves forward to the expose position.
- At the same time the X-ray control enters preparation mode.
- Once the cassette is in position, most times a short time delay is operated before permitting the actual exposure request. This is to allow any vibration or shaking to subside.
- The table waits for the 'ready' or 'preparation complete' signal from the X-ray control.
- When 'ready' is obtained from the X-ray control, and the cassette is in position, the grid will commence oscillation on pushing the 'expose' button.
- On operation of the grid-controlled exposure switch, the table sends the 'expose' request to the X-ray control.
- Once the exposure is completed, the X-ray control sends a 'time up' signal to the table. The cassette then returns to its initial position in the radiation shield area.
- Not all tables have an automatic return on end of exposure. The radiologist instead releases the exposure button after observing the exposure is completed. This especially applies in non-motorized movements, where the radiologist moves the cassette manually.

- In case the exposure button is released during exposure, this will terminate the exposure, returning the cassette to the safety area.
- At the end of a radiographic exposure, the X-ray control has a delay to allow the X-ray-tube filament temperature to drop from radiographic level to fluoroscopic heating.
- Once the X-ray control filament reset time delay has finished, and the cassette is in the radiation shield area, fluoroscopy may be resumed.

d. Safety interlocks

To provide safe operation, and reduce operator error, the following interlocks may be provided.

Radiation protection

- A switch is fitted to prevent radiation unless the image intensifier is correctly mounted. This is on tables where the image intensifier may be dismounted. This is required to enable some serial changers to be 'parked' when using the system as a Bucky-table.
- A safety switch to disable operation, when the serial changer is moved out of alignment with the X-ray beam. This is required for systems that allow the serial changer to be 'parked' for Bucky-table operation.
- On some smaller tables, a provision is made to allow the undertable tube to rotate for service, or to enable use with a wall Bucky. A safety switch is fitted to ensure in correct position for fluoroscopy.
- In many tables, a protective cover with a switch is fitted over the slot for the undertable Bucky. In these tables, the Bucky must be parked at the foot end of the table, and the Bucky-slot cover closed, to permit fluoroscopy.
- In case the cassette is in the 'loading' position, no exposures are permitted.
- Where an exposure count has been completed for a cassette, further exposures are prohibited until a fresh cassette is inserted.
- Unless the cassette is correctly positioned in front of the X-ray beam, exposure is not permitted. Note, in some cases, this is especially important in case the cassette motor drive system is not correctly adjusted.
- On some tables, a 'preparation for fluoroscopy' switch must be operated before proceeding. This switch is cancelled automatically on selection of a non-fluoroscopy technique, so the table must be deliberately re-selected every time before use.
- The X-ray automatic collimation has a facility to allow for manual control of the exposure field. This allows the field to be reduced, during fluoroscopy, and held in that position when exposing on film. Manual control is not permitted outside the area observed during fluoroscopy.
- On some remote operated tables, a key switch is fitted to allow over-ride of automatic collimation for special examinations. This switch must be in 'automatic' mode to allow fluoroscopy.
- On remote controlled tables, exposure is prohibited while the X-ray tube height is being adjusted.
- Many remote controlled tables permit the X-ray tube to rotate for other requirements. (For example, to aim at a wall Bucky). Fluoroscopy operation is disabled in this mode.
- While fluoroscopy is permitted during movement of the table or table top, this is not permitted for film operation, and all possible movements are normally locked out or disabled during radiography.
- The X-ray control is fitted with a fluoroscopy timer, usually for five minutes maximum. Some tables may have a duplicate timer for this operation.

Mechanical protection, for patient and table

- With conventional tables, a compression cone is attached under the serial changer. When in use, all compression and other movements are applied manually by the radiologist. In case the vertical movement of the serial changer is locked, tabletop movements are disabled. In another version, in case tabletop movement is energized, the vertical lock for the serial changer is immediately released.
- For remote controlled tables, the compression device is motor driven. The motor power is limited to avoid excessive compression. On movement of the serial changer or table top, the motor immediately retracts the compression cone. In another version, the motor is controlled by electronic measurement of the compression force. In case the patient is moved under compression, the motor will operate to ensure compression remains constant. These tables allow the radiologist to preset the maximum compression that may be used for a particular patient.
- A patient may place the hand outside the tabletop area. Particularly with a remote controlled table, this can lead to serious injury. In some tables, a light beam is used to detect a hand gripping the underside of a tabletop. In other systems a gel filled protective buffer is employed. This buffer has a sensor to register any change of pressure, and immediately disable the relevant tabletop movement.

- When the table is rotated, eg, from horizontal to vertical, there is the possibility of collision with an object, such as a stool etc. To reduce this possibility, a number of anti-collision systems have been used. This may be via a plate or bar on the table-base, which operates a microswitch. In other systems, a pressure pad may be installed on the floor under the table. None of these systems are perfect, and care is required to keep the floor area clear when operating the table.
- The tabletop longitudinal travel may extend a considerable distance, both towards the head or foot end. When the table is tilted, a series of camoperated switches determine if a collision with the floor or ceiling is possible. In this case, either the table rotation is disabled, or else the tabletop is automatically retracted to a safe position. In many remote controlled tables, where a computer is used, the relevant positions of tabletop and table rotation are continuously measured. Depending on parameters entered into the computer during installation, the computer decides when operation is unsafe.
- 'Belt and braces'. A number of remote controlled tables have an emergency limit switch installed. In case the table movement does not stop after reaching the correct limit of operation, further movement trips the emergency stop, disabling the table. An operator controlled emergency operation switch is also installed at the table, as well as the control panel. This allows the operator to immediately disable all table movements in case of any unusual operation.

PART 11 THE AUTOMATIC FILM PROCESSOR

Contents

a. X-ray film properties
b. The automatic film processor
c. Processor developer section
d. Processor fixer section
e. Processor wash section
f. Processor film dryer
g. Other processor modes
h. Processor chemistry

a. X-ray film properties

- Standard X-ray film is photographic film, coated on both sides of a polyester film base. This is called 'double emulsion film'.
- A variation, 'single emulsion film', is coated on one side only. A typical application is mammography, where maximum possible image sharpness is required.
- The photosensitive material is 'silver halide', suspended in the form of small crystals in a gelatin solution. The silver halide consists of approximately 90 to 99% of silver bromide, and about 1% to 10% of silver iodide. The exact composition depending on the manufacturer and the desired characteristics.
- X-ray film has relatively poor sensitivity to X-rays. As a result, 'intensifier screens' are used to convert the X-ray energy to light energy. In a typical X-ray cassette, the film is placed between two intensifier screens. By using double emulsion film, light from the intensifier screen on each side of the film sensitises that particular layer. This process effectively doubles the film / intensifier screen sensitivity to X-rays, and permits greater film contrast.
- When an exposure is made, light from the intensifier screens cause the grains of silver halide to form a 'latent image'. Development of the film greatly magnifies this latent image, to show the visible image in the form of black metallic silver.
- After the image has been developed, the resultant image is then 'fixed'. Fixing removes the unused silver halide, which would make the film appear milky or cloudy, leaving behind the metallic silver. The fixing solution also contains a substance to harden the gelatin and make it tougher. An acid component stops any further development of the film.

- A major component of fixer is 'thiosulphate'. This is commonly called 'hypo' after an earlier chemical name of 'hyposulphite of soda'.
- After fixing the film, the film is washed to remove residual fixer, and then dried prior to viewing.
- 'Regular' X-ray film is biased to the blue region of visible light, with very poor sensitivity towards the red region. This allows the use of a red safelight in the dark room. 'orthochromatic' film is extended to the green region, and 'panchromatic' has its sensitivity extended to the red region.
- Orthochromatic film is used with current intensifier screens that have a green spectral response.

b. The automatic film processor

The following description is for a basic film processor. Larger units will have extra functions to maximize film processing time, or energy saving functions. The principle of operation, however, remains the same.

- The processor consists of three separate tanks. These contain in turn the developer, fixer, and wash water.
- The developer and fixer solutions are kept heated to a precise temperature to suit the film and chemistry used.
- A series of rollers and crossover plates transport the film through these three sections, then finally through a heated air dryer before ejecting the processed film.
- As the film passes through the chemical solutions, the developer and fixer becomes less concentrated, and requires automatic top-up or 'replenishment' to retain the correct concentration. This is done by precision metering pumps. The time these pumps operate depends on the size of the film entering the processor.
- The wash water is continuously replenished, to insure minimum residual fixer content.

c. Processor developer section

Refer to Fig E–44.

- The dotted line indicates an area outside the developer section.
- The developer supply is a pre-mixed solution of developer concentrate and water.
- When a film is inserted, sensors at the insertion point determine the film width. As the film travels into the processor, this determines the length. The electronics then calculates the developer supply pump operation time.
- The developer solution is kept under circulation by another pump. This operates continuously when the processor is ready to accept films.

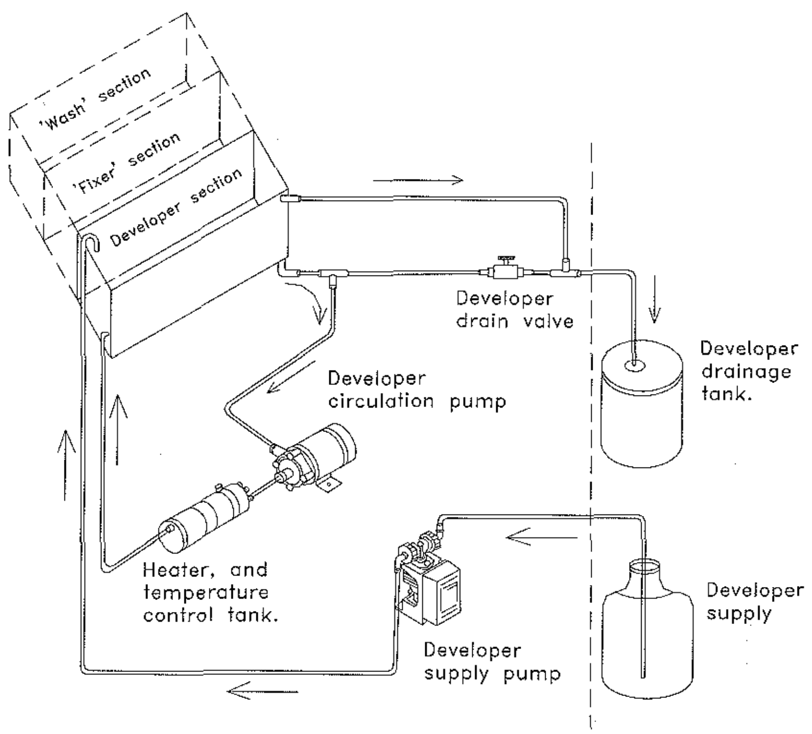


Fig E–44. Processor developer section

- Developer solution passes from the circulation pump back into the tank via a temperature controlled heater. (Or heat exchanger.) The developer temperature is normally set between 34 to 36 degrees Celsius depending on developer and film combination.
- As fresh developer is pumped into the tank, excess used developer will flow from the top of the tank to a holding tank for used developer. (In some countries, though not recommended, this instead may go direct to the drain.)
- For service to the processor, a drain valve or tap is provided to empty the developer tank.

d. *Processor fixer section*

Referring to the diagram of the fixer section, Fig E–45

- The fixer supply is premixed fixer concentrate and water.
- The fixer supply pump is also controlled by the measurement of the film as it enters the processor.
- The rate of fixer replenishment to developer is about two to one. To obtain this the fixer pump will operate for twice the time as the developer pump. In some systems, two fixer pumps operate in parallel for a similar time as the developer pump. Other systems may instead have a larger capacity pump for the fixer.
- The fixer solution is passed through the heater and temperature control tank by the fixer circulation pump. The heater tank in this case is a dual chamber system. The major chamber of the tank is devoted to heating and controlling the developer solution. A smaller chamber of the tank allows the fixer solution to be heated, but at a slower rate than the developer. (In some larger systems, separate heating tanks are provided for fixer and developer).
- As fresh fixer is pumped into the tank, depleted fixer is passed into a storage tank or else a silver recovery unit. **Fixer contains components that are harmful to the environment, and health regulations forbid allowing this chemical to be dumped into the drainage system.**
- For service to the processor, a fixer drain valve or tap, is supplied to empty the fixer tank.

e. *Processor wash section*

Referring to the diagram in Fig E–46

- The water flow control valve or tap regulates the replacement rate of the wash water.
- A water filter is highly recommended to prevent sediment entering the processor.
- When a film is inserted, the solenoid operated 'water on' control valve operates to allow the wash water to be refreshed.

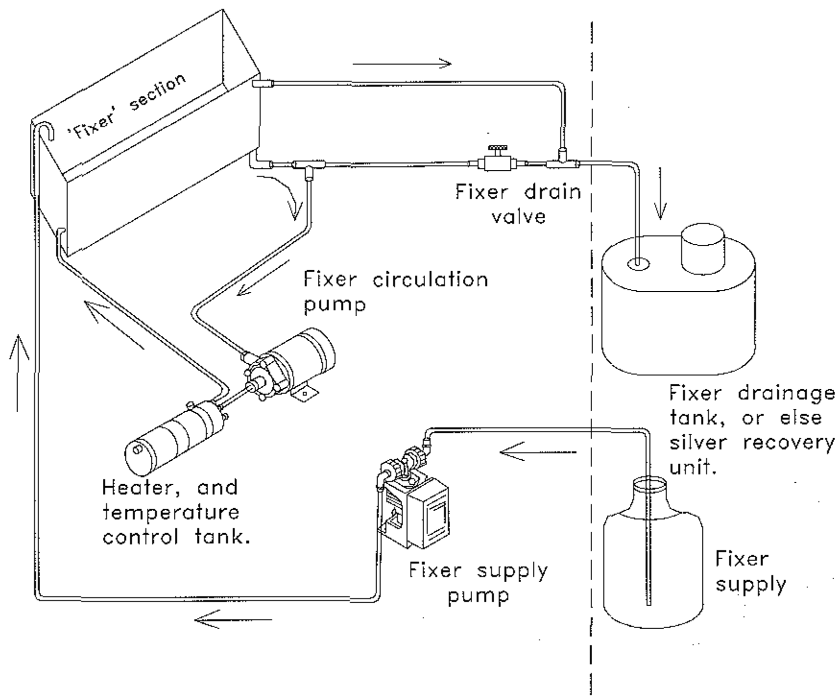


Fig E–45. Processor fixer section

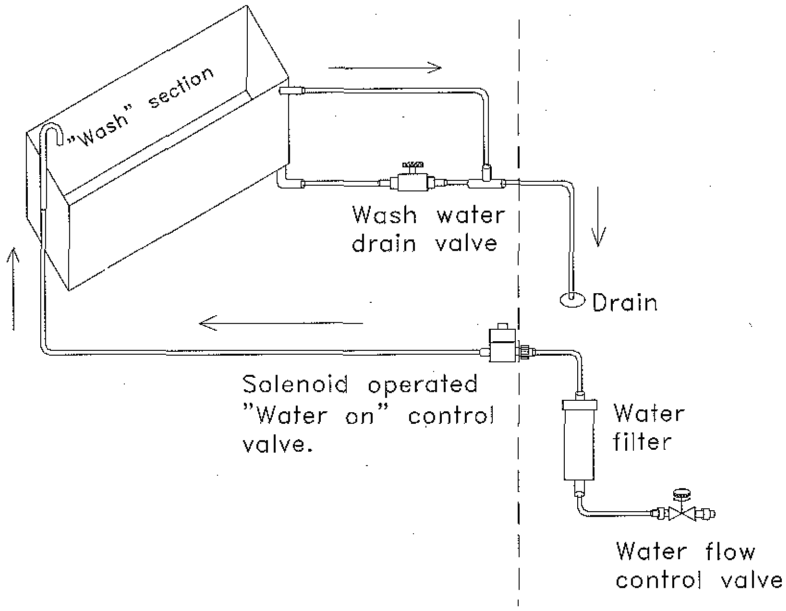


Fig E–46. Processor 'wash' section

- A timer extends the time that water flows for several minutes, and then closes to save excessive water consumption.
- Water enters the wash tank from the top via an air gap. This is a safety requirement, and prevents possible transfer of the wash water back into the water reticulation system.
- As the film passes through the transport rollers into the wash tank, the rollers remove almost all of the fixer from the film. The wash water removes the small remainder. As the concentration of fixer in the wash water is very small, the wash water is permitted to exit to the sewage drain.
- **Note.** Care should still be taken that this wash water does not enter drinking water, by draining towards where well water is obtained.
- A wash water drain valve or tap is provided for service to the processor.

f. Processor film dryer

- The transport rollers pass the film from the wash tank through the dryer section and into the film receiver.
- The dryer has a temperature-controlled heater. Air is blown past this heater and onto the film, removing the residual moisture.
- The actual temperature setting may be adjusted to suit local conditions. Eg, areas of high humidity can require increased drying temperature.
- As a safety precaution, the heating element has an 'over heat' sensing switch, as a backup to the temperature control for the heater.

g. Other processor modes

- On power up, a time delay is activated to ensure an adequate preparation time. During this period developer temperature is stabilized, and the dryer temperature is raised to the required level.
- During start-up preparation, an added amount of developer and fixer may be supplied to each tank. After about an hour of operation, this may be repeated, although a film is not inserted.
- The film transport motor operation time may be determined by the film size and processor mode. In some systems, although not processing a film, the motor will start up and run for a short period. This is to optimize condition of the rollers.
- Depending on make and model, an economy or standby mode will be entered after a preset time.
- Again, depending on make and model, after a long preset time (usually eight hours), a complete automatic shutdown may occur if the processor has not been used.
- Temperature setting may be reset to suit different film specifications, eg, in case single emulsion films are being processed. To accomplish rapid reset to a lower temperature, cold water circulates through a heat exchanger section of the heater and temper-

ature control tank, or tanks. The temperature setting in a modern processor may be adjustable from 25 to 40 degrees Celsius, but is normally around 34 degrees Celsius.

- Some processors measure ambient temperature and humidity. This information is used to help optimize the dryer temperature.
- While some processors may have a separate (or combined) heater for the fixer, fixer temperature is less critical than developer. In some cases, the fixer may be kept warm simply by heat conduction, from the developer tank to the fixer tank.
- Some processors have a rinse water replenishment pump. This allows for a change of rinse water in a small trough under the film crossover rollers. In effect, this provides a small washing action when film is fed from the developer tank to the fixer tank. In some units, this is repeated for transfer from the fixer tank to the wash tank.
- 'Dwell time' is the amount of time the film is in the chemistry. Modern film processors can run as low as 45 seconds from time of the film leading edge 'in' to leading edge 'out'. 45, 60, 90, and 120 second cycles are most common. Single emulsion films may require a longer dwell time due to the thicker emulsion layer used. Typical of this is mammography film, using 120 second dwell time.
- Height of chemicals in the developer and fixer troughs may also be monitored. This can be via a float with a magnet attached, passing over a sensor.
- Modern processors now make considerable use of microprocessors. This allows for direct input by the operator for the required mode of operation, as well as displaying status and error messages.

h. Processor chemistry

- Processor chemicals are provided in concentrated form. For use, they are mixed with water, preferably filtered water, to a recommended 'specific gravity'. A floating specific-gravity gauge or 'hydrometer' is used to ensure the correct ratio of water to solution is obtained.
- When films pass through the processor, chemicals are depleted. Also a small amount is carried over to the next tank. In the developer section, oxidation occurs, and the bromide level increases. To compensate, a metered amount of developer is added for each film processed. This is called 'replenishment'.
- Developer solution is initially highly reactive until the bromide level stabilizes. When starting up a new processor, or replacing suspect chemicals with a fresh solution, 'starter' solution is added. This brings the bromide level to the correct operating level.
- In case the developer replenishment rate is excessive, then the bromide level falls, and results in overactive chemistry.
- Low developer replenishment results in low activity chemistry, and poorly developed films.
- Fixer also loses its ability to harden films, and requires replenishment.
- Typical replenishment rates for a 35 by 43 cm film are: Developer 45 to 65 cc, fixer 80 to 110 cc. The exact rate depends on the film, chemicals used, and processor make and model.