CHAPTER

CLINAC 1800, MEDICAL LINEAR ACCELERATOR
3.1 GENERAL:

Clinac 1800 linear accelerator from Varian Associates, Palo Alto, CA, U.S.A. has been designed to deliver therapeutically useful beams of x-rays and electrons with characteristics as dictated by conventional radiotherapy techniques. This accelerator has been designed to provide rectangular and square fields which can be used with great flexibility for multiport wedged and non-wedged treatment, rotational treatment, total and hemi body treatment fields, extra large mantle fields and many other sophisticated treatment. In the Clinac-1800 installed at Kidwai Memorial Institute of Oncology, Bangalore, India, electron energies of 6,9,12,16 and 20 MeV and photon energies of 6 and 18 MV are available. The major components of the Clinac 1800 are gantry, stand,modulator,card rack,console and the patient support assembly (Clinac 1800 specification catalogue, No.1665C 9/87). The treatment beam is generated by a linear accelerator located in the gantry. The standing wave accelerating guide of this linear accelerator uses a side-coupled cavity design which creates a resonant standing-wave condition and minimizes power loss in the accelerator. The entire assembly is mounted in a rotating gantry with 100 cm target to axis distance (TAD). The electron beam from the accelerator passes through a bending magnet system situated in the upper gantry area which provides completely achromatic electron beam bending about a 270° path and
consists of electromagnet with appropriate energy defining slits.

3.1.1 GANTRY AND COLLIMATOR:

The x-ray and electron beam are generated by a linear accelerator located in the gantry. The gantry may be rotated clockwise or anti-clockwise through 360°. The upper gantry area contains the magnet system for beam bending and the beam collimating assembly. The magnet system provides achromatic electron bending about a 270° path and consists of an electromagnet with appropriate energy defining slits. The lower gantry area provides for attachment for a counterweight. The major components in a linear accelerator are shown schematically in Fig. 3.1.

The collimator assembly provides variable collimation via two pairs of movable collimators which traverse arcs approximately normal to the radiation beam. Parallel upper collimator jaws move apart to define one dimension of the radiation field whereas the lower collimator jaws defines the other dimension providing a field size from 0 to 35 cm at a target to skin distance (TSD) of 00 cm. Independently adjustable upper collimator jaws facility is available in this machine at our institute which allows each upper collimator to be positioned upto 10 cm past the beam centerline. For electron beams, five electron applicators are available which define field sizes of 4x4, 6x6, 10x10, 15x15, 0x20 and 25x25 cm² at the isocenter. Also, there is an additional feature made available on our machine which allows elec-
Fig. 3.1 Block diagram of the Clinac-1800 medical linear accelerator.
tron arc therapy using an electron arc applicator. The dose rate of all the beams can be varied from 80 MU/sec to 400 MU/sec in five steps of 80 MU each. A general view of clinac 1800 is shown in Figs.3.2.

3.1.2 ACCELERATOR STAND:

The stand unit, in addition to being the isocentric support point for the gantry provides housing for RF generation unit, RF transmission and attenuation equipment, the stand signal patch panel and a water cooling system. It also supports a gas dielectric system, pneumatic system, beam steering and focusing power supplies. Mode control equipment, machine motion and control equipments are also housed in the stand.

3.1.3 MODULATOR:

The modulator contains a high voltage power supply, a voltage regulator, a Pulse Forming Network (PFN) with a thyatron switch tube and protective interlock circuits. It also contains the majority of the circuit breakers and transformers associated with the overall ac power distribution system. A pulse generator is also located in the modulator cabinet, which produces trigger pulses used in the system.

3.1.4 CARD RACK:

The card rack consists of a number of printed circuit
Fig. 3.2 Clinac-1800 Linear Accelerator at Kidwai Memorial Institute of Oncology, Bangalore.

Fig. 3.3 Control Console of Clinac-1800 Linear Accelerator with patient monitoring close circuit television system.
boards which provide interface between the console and various other units in the system. A monitor panel, which comprises the front of the assembly, consists of switches indicators and test points. A patch panel provides connection points between the card rack and other units, and a BNC connector jack panel provides convenient oscilloscope connection points for measurement of system parameters. The card rack power supply, self contained in a separate unit from the card rack, provides all of the operating voltages required for the card rack.

3.1.5 CONTROL CONSOLE:

The Clinac 1800 is controlled by a control console which contains digital displays indicating dose, time, and other parameters. The compact control console allows selection of modality and electron or photon beam energy, and permits setting of parameters such as the integrated dose to be delivered, the time of treatment, and the stop angle for arc therapy. It contains lighted indicators which signify the status of the interlocks within the system. The control console along with the close circuit television to monitor the patient during treatment are shown in Fig.3.3.

3.1.6 PATIENT SUPPORT ASSEMBLY:

The PSA treatment couch has four motions which are motorized, utilizing variable speed motors controlled from a hand pendant
3.2.1.1 KLYSTRON MODULATOR SUBSYSTEM:

The purpose of Klystron Modulator Subsystem is to generate the high voltage beam-power pulse to the cathode of the klystron amplifier simultaneous with the application of the rf drive pulse to the klystron amplifier input port. A train of klystron triggers are generated in the control console and routed through cardrack to the modulator where they fire a thyratron that discharges a pulse forming network (PFN) into the primary of the pulse transformer in the stand. The discharge of the PFN creates a 11 to 13 KV pulse that is stepped up by the pulse transformer and applied to the cathode of the klystron.

3.2.1.2 RF SUBSYSTEM:

The rf subsystem generates and supplies pulses of high power microwave rf energy to the accelerator guide. A low level 2856 MHz signal from the rf driver is applied to the klystron's input. At the same time a high voltage beam-power pulse is applied to the klystron's cathode. The klystron amplifies the rf input signal to produce high power rf pulses (up to 5.5 MW). The level of output rf power is a function of cathode voltage and rf drive power. The amount of rf energy required to establish the desired electric field strength in the accelerator guide varies, in relation to the electron energy selected. The rf energy leaving the klystron is transmitted through waveguide to a four port.
The circulator routes all the energy entering it around counter-clockwise to the next port. The AFC subsystem compares the phase of the input and reflected rf power. Any phase changes are converted to correcting voltages that are fed back to the rf driver to keep it tracking the resonant frequency of the accelerator. The high power, microwave rf energy transmitted through the waveguide and various assemblies in the rf subsystem develops very intense electric fields. To prevent arcing, the rf subsystem is pressurized by the gas dielectric (SF6) subsystem.

3.2.1.3 ELECTRON ACCELERATION SUBSYSTEM:

The electron accelerator subsystem consists of the gridded gun and the accelerator guide assemblies (Fig.3.4). The gridded gun is a triode that injects electrons into the accelerator. The cathode of the gun is held at either -5 KV or -18 KV, depending on the energy selected with respect to the accelerator, to give the injected electrons the proper initial velocity. When the grid pulse from the gun driver is applied to the grid, the gun turns on and the electrons are injected through the anode into the accelerator guide. The accelerating guide is of standing wave type, which, by using side cavities to couple together the accelerating cavities, is considerably shorter than the earlier travelling wave type guide. The cavities within the guide are resonant at the frequency of the applied r.f viz. 2856 MHz. This rf energy, resonating in the cavities, develops changing electric field potentials across each of the cavities. When electrons are
injected into the accelerator guide, they are forced to travel the length of the guide in synchronism with the energy. Before leaving the guide the electrons are accelerated to nearly the velocity of light.

3.2.1.4 GUN DRIVER SUBSYSTEM:

The main purpose of this system is to turn the accelerator's electron-injecting gridded gun 'ON' and 'OFF' coincident with the application of rf energy to the accelerator guide. In addition, the gun driver subsystem respond to commands from dosimetry subsystem to occasionally delay turning on the gun.

3.2.1.5 BEAM SHAPING SUBSYSTEM:

The purpose of this subsystem is to precisely define the shape of the x-ray or electron beams applied to the patient.

A. PHOTON BEAM SHAPING SUBSYSTEM:

X-ray beam, generated by high energy electrons striking the target, passes through a series of tungsten collimators and is confined to the size of their aperture. Firstly the x-ray beam is confined to a projected 30 cm cone by the primary collimator (Fig.3.4). The x-ray beam then passes through a flattening filter, located on a carrousel, which makes the beam uniform in flux intensity across its width. After passing through the ion
Fig. 3.4 Electron accelerator and bending magnet in Clinac-1800 linear accelerator.
chamber, the beam leaves the gantry unit and enters the collimator unit, where it encounters the secondary collimator. Leaving the secondary collimator, the beam enters the two pairs of motor driven collimator jaws (Ref. Fig. 4.27 in the later part of the thesis).

B. ELECTRON BEAM SHAPING SUBSYSTEM:

The shaping of the electron beam, when it is used directly for therapy, is the same as the shaping of the x-ray beam with two differences. 1) A scattering foil is used in place of the flattening filter to scatter the electron beam and give it an useful width. The ion chamber provides some additional scattering also. 2) An electron applicator accessory is attached to the collimator unit to give final definition to the beam just before it enters the patient.

3.2.2 SUPPORT SUBSYSTEMS:

The support subsystems perform those functions that support the operation of the primary subsystems and this includes the following subsystems:

3.2.2.1 POWER DISTRIBUTION SUBSYSTEM:

The power distribution subsystem accepts 3-phase 208 Vac Power from the customers main circuit breaker and distribute one, two, or all three phases to various sections of the machine,
protects various sections of the machine from overload with circuit breakers, supplies power to various sections of the machine in a controlled relay sequence and disables the machine when a fault or safety interlock circuit commands it.

3.2.2.2 PNEUMATIC SUBSYSTEM:

The pneumatic subsystem supplies the pressurized air that operates the shunt 'T' drive in the stand, the target drive mechanism in the gantry and to set the pin in the carrousel. In Clinac 1800 the energy switch is also operated by this subsystem. The air supplied to the shunt 'T' drive raises and lowers a cylinder that sets the variable rf waves at the proper position for a particular mode and energy. The air supplied to the target drive mechanism extends the target into the electron beam in the x-ray mode and retracts it during the electron mode operation. Most of the components of the pneumatic subsystem are contained in the air regulator assembly in the stand. The compressed air from this assembly is piped to the equipment in the stand and gantry. The air to the regulator (approximately 50 to 60 psi) is provided by either this facility or by an optional air regulator in the Clinac. If the air pressure falls below a certain limit, the 'AIR' fault lamp on the console lights up. This fault will not shut the machine down; but provides a status indication only.

3.2.2.3 VACUUM SUBSYSTEM:

There are two parts in the vacuum subsystem: The part in
The stand keeps the klystron volume evacuated; the part in the gantry keeps the shared volume of the gun, accelerator, and bending magnet evacuated. The evacuation of these assemblies prevents arcings and prolongs the life of the gun and klystron cathodes.

3.2.2.4 AIR VENTILATION SUBSYSTEM:

Air at room temperature is circulated through the stand and gantry by two fans to keep certain components at proper operating temperatures. The modulator cabinet is cooled by two fan assemblies and the dc power supply by one fan.

3.2.2.5 GAS DIELECTRIC SUBSYSTEM:

The gas dielectric subsystem supplies sulphur hexafluoride (SF6) gas under pressure to the waveguide in the rf system between the klystron window and the linear accelerator window, to prevent high-voltage arcings. All of the components that make up the gas dielectric subsystem are contained in the gas dielectric assembly in the stand.

3.2.2.6 WATER SUBSYSTEM:

The water subsystem cools certain components in the stand and gantry that require stable temperatures for proper machine operation. Demineralized water is forced through these compo-
ments by a submersible pump located inside an 18-gallon water tank. The water first passes through one half of the heat exchanger to be cooled and then through the components. The water subsystem operates on demand; the amount of city water that passed through the other half of the heat generated by the machine.

3.2.3 CONTROL SUBSYSTEMS:

The control subsystems direct and regulate the operation of the primary subsystems; these subsystems are:

3.2.3.1 MODE CONTROL SUBSYSTEM:

At the console, the operator can select five electron energy modes and two x-ray energy modes. The purpose of the mode control subsystem is to reconfigure some assemblies and change the operating levels of others when different energies are selected. When an energy is selected, Binary Code Decimal (BCD) programming commands are sent from the console logic to the mode control assembly in the stand and to the program boards in the card rack; at the same time, the calibration routine is started, which checks the dosimetry subsystem for proper operation. The coded command sent to the card rack selects one of seven program boards; the selected program board delivers preset signals, voltages, or resistances to the assemblies.
3.2.3.2 POSITION READ OUT SUBSYSTEM:

The position readout subsystem, which monitors and displays the position of the gantry and collimator and the dimension of the collimator jaw openings.

3.2.3.3 AFC SUBSYSTEM:

The purpose of the AFC subsystem is to keep the frequency of the rf forward power at the resonant frequency of the accelerator guide. This is accomplished in a phase-locked loop, by sampling and comparing the phase of rf forward power with power reflected off the guide. Any phase difference is amplified and integrated to produce an error signal which is used to control the frequency of the rf driver. When required, the AFC tuning voltage may be manually adjusted by tuning the red AFC control on the monitor panel. The AFC tuning voltage in both the automatic AFC and manual modes is displayed on the meter directly above the red AFC control.

3.2.3.4 TRIGGER SUBSYSTEM:

The trigger system produces five precisely timed and synchronized trigger pulses and one control command. The trigger system establishes the timing sequence that synchronizes the overall operation of the system, establishes energy levels and dose rates, and regulates the dosage delivered. The triggers and
command produced by the trigger generator logic are: (i) RF drive trigger (ii) Klystron gate (iii) Klystron pulse repetition gate (iv) Gun control command (v) Time dose calibration check (vi) Sync trigger (vii) AFC trigger.

3.2.3.5 BEAM STEERING SUBSYSTEM:

The beam steering subsystem uses steering coils to guide the electron beam through the accelerator and bend magnet, and on to the target. There are three sets of steering coils: buncher, position, and angle. The buncher coils are located at the gun end of the accelerator guide. The steering power supply in the stand delivers preset currents to the coils. Program boards in the card rack set the level of the currents, and as different energy modes are selected, different preset program boards are connected to the steering power supply. The currents flowing in the steering coils generate magnetic fields that steer the injected electron to the center of the accelerator guide. The position steering coils, located at the bellows end of the accelerator guide, steer the electron beam into the bend magnet and onto the target; these coils control the position of the electron beam as it strikes the target. The angle steering coils, located within the bend magnet assembly, control the angle at which the electron beam strikes the target. The currents delivered to both sets of coils are controlled by program boards that set the outputs of the steering power supply, as is the case with buncher steering. However, the position and angle coils are also part of a beam steering servo-loop that includes the ion chamber and
Because the purpose of the clinac-1800 is to deliver a therapeutically useful beam of radiation, a system is needed to monitor the quantity and uniformity of that radiation. The dosimetry subsystem monitors and displays both of these parameters; the quantity of radiation is expressed in RADS and the uniformity is expressed as a percentage of asymmetry. The dosimetry subsystem starts with the ion chamber, which is "kapton" in our machine. As radiation passes through the ion chamber, it ionizes N₂ gas in proportion to the amount of incident radiation. By applying a high voltage across parallel plates within the chamber, a current is collected; this current is calibrated against a known detector located 1 meter from the target. The ion chamber has 5 plates, of which 3 are at a potential of -500v and the other two are collector plates that are referenced to ground through the input of operational amplifier. The spacing between the plates is approximately 1.02 mm. The collector plates have 4 independent sections for collecting ion current in different parts of the radiation beam. All four sections are used in photon e, whereas only the two inner sections are used in the electron mode. One of the collector plates is turned 90° in relation to the other in order to detect beam movement in both the radial transverse planes.
The A and B collector sections are used for RADs 1 exposure monitoring and the determination of beam angle, which is related to the incident angle of the electron beam striking the target (in the radial plane). The angle position signals provide feedback to the beam steering subsystem.

3.2.3.7 MOTOR CONTROL SUBSYSTEM:

There are nine DC motors controlling the nine motions of the various assemblies involved in the treatment set up. The nine motions are: Gantry rotation, couch lift, collimator rotation, upper collimator dimension, lower collimator dimension, PSA rotation, couch lateral movement, couch longitudinal movement, independent upper jaws movement.

3.2.3.8 ARC THERAPY SUBSYSTEM:

The arc therapy subsystem is used only during rotational, or arc therapy. It enables the machine to deliver a preset dose over a preset desired angle of arc; the dose per degree can be set anywhere from 0.5 to 5.0 cGy. The dose per degree is monitored, and the dose rate servo corrects it as necessary if the dose per degrees falls below a rate that cannot be servoed, the under dose fault will be triggered. Both of these faults will terminate the treatment. The arc therapy control servo logic consists of two decode counters that set gantry speed and dose rate (repetition rate), and three counter/comparator circuits: arc dose rate, arc excess dose rate, and stop angle. The binary coded decimal
(BCD) output of the front panel RADS/DEGREE thumb wheel switches is applied to both the gantry speed decoder and the repetition rate (dose rate) decoder. These decoders are hardwired to produce gantry speed and repetition rate code. Arc therapy is completed when the gantry has rotated a preset number of degrees with correct radiation delivered for each degree. When the number displayed on the position-readout agrees with the preset number on the STOP - ANGLE thumb wheel switches, arc therapy is terminated by inhibiting the output of the gantry speed select decoder.

3.2.3.9 FAULT AND INTERLOCK SUBSYSTEM:

The fault and interlock subsystem monitors various circuits in the Clinac to provide both status and malfunction indications at the console unit. The subsystem consists of the fault and status matrix assembly in the console unit and fault and status condition detection circuits located throughout the machine. When a fault or status condition is detected, a fault and status matrix indicator lights, and in most cases, beam-on operation is inhibited.

3.2.4 X-RAY TARGET:

In the x-ray mode of operation the tungsten/copper target is extended into the high energy electron beam near the point where it leaves the bend magnet. When the electrons strike the target,
they pass close to the target nuclei giving up the energy in the form of bremsstrahlung x-rays emitted in the forward direction. The x-ray beam has a continuous spectrum with a maximum energy dependent on the energy of the accelerated electrons incident on the target. The target is positioned in and out of the electron beam path by a pneumatically operated target drive mechanism. The thin and thick areas of the target is inserted for 6 and 18 MV x-rays respectively.

3.2.5 ION CHAMBER:

The ion chamber consists of five metalised plates stacked one on top of another and mounted within a sealed container. The collector plates have four collector segments each. The A,B,C and D segments are used to monitor dose rate, integrated dose, and beam angle; the E,F,G and H segments are used to monitor beam position. (Fig.3.5). As radiation passes through the ion chamber (and the five plates) it ionizes dry nitrogen within the chamber. This ionization produces a current output from the various segments which is proportional to the flux intensity of the radiation passing through those segments.

3.3 ACCESSORY INSTRUMENTS:

3.3.1 CAPINTEC EXPOSURE/EXPOSURE RATE METER:

The Capintec model 192 exposure rate meter (Capintec Inc, Pittsburgh, USA) is a wide purpose extremely accurate and sensi-
Fig. 3.5 Ion chamber collector plates in clinac-1800 linear accelerator.
tive precision instrument. It provides a direct readout of x-ray exposure or exposure rate on a digital panel meter from probes of dimensions from 0.1 cc to 3000 cc. Its range is from 2 mR to 2000 R. A knob marked compensation allows to input correction factors for temperature, pressure and calibration into the unit to obtain directly the corrected reading. Upto 3 calibration constants can be preset for 3 different probes. Its linearity is ±0.1% of full scale and accuracy is with in ±0.5%. Full scale electrometer ranges are available from 2.0 nC to 2000 nC. Noise level for 0.65 cc chamber and 25 feet attached cable is typically less than ±2.0 mR/min. Ion collection supply voltage is in the form of a 300 Volt centre tap carbon-zinc battery (Instruction Manual for Capintec Exposure/Exposure rate meter, Capintec, Inc.).

3.3.2 IONIZATION CHAMBER PR-06G:

PR-06G ionization chamber is a Farmer replacement chamber with air volume of 0.65 cc; it is an air equivalent ionization cavity suitable for therapeutic grade calibrations and measurements of radiation fields in clinical applications. The outer dimensions of this probe are the same as that of Farmer secondary standard ionization chamber. Its sensitivity is 0.6nC/R and maximum resolution is 0.001 R. Leakage current is less than 10^-14 A. Its wall thickness is 0.20 mm (50 mg/cm²) and its diameter and length are 7 mm and 20 mm respectively. The Capintec dosimeter with chamber is shown in Fig.3.6.
Fig. 3.6 The Capintec dosimeter with 0.6 cc chamber.

Fig. 3.7 The RDM-1F dosimeter with 0.6 cc Farmer type chamber and parallel plate chamber.
3.3.4 PRECISION ELECTROMETER RDM-IF:

The RDM-IF is a precision electrometer from Therados, Uppsala, Sweden with digital display of current or charge. It is designed to be used with ionization chambers for dose or dose rate measurements in radiotherapy. The electrometer of RDM is a varactor bridge input operational amplifier connected as current to voltage or charge to voltage converter depending on the type of mode selected. The varactor bridge input has a very low bias current ($10^{-12}$ A). The Electrometer is calibrated to give accurate readings of current and charge. Its maximum resolution is $10^{-12}$ C and accuracy is $\pm 0.2\%$ in charge mode and in current mode the maximum resolution is $10^{-12}$ A. Bias voltage available is 200/400 volts with a polarity selection switch. The detector is connected to the electrometer input BNC connector and bias voltage is given through the banana jack (Instruction manual, Precision Electrometer RDM-IF, Instrument AB Therados). The RDM 1F dosimeter and accessories are shown in Fig. 3.7.

PTW B23333 Ionization Chamber is a 0.6 cm$^3$ volume Farmer type chamber used with RDM 1F dosimeter. Its internal length is 21.9 mm, internal radius is 3.05 mm, outer radius is 7 mm and its wall and cap are made of PMMA. The Co-60 build up cap and the machined build up caps of 1.5 cm and 3.3 cm water equivalent thickness for 6 and 18 MV photons are shown in Fig. 3.8.

PTW B 23344 plane parallel Chamber has a diameter of 16 mm and the plate separation is 1.5 mm. This thin walled plane
Fig. 3.8 Build up caps for co-60, 6 MV and 18 MV photons.

Fig. 3.9 Huestis Styro-former.
parallel chamber is useful for electron dosimetry, build-up region study and surface dose measurements.

3.3.5 THELMEDOR MODEL 6000 TLD READER:

The THELMEDOR (Thermoluminescent Medical Dosimeter Reader) Model 6000 is the TLD reader (DRP, BARC, INDIA) used in this study can measure TL phosphors such as Lithium Fluoride or Calcium sulphate in the form of powder or chips. TL material are heated in the heater pan and the light released from the materials is measured by a photomultiplier tube. The integrated TL output is proportional to the total dose received by the TL dosimeter. The digital read-out is plotted against the radiation exposure in the form of calibration graph. By adjusting the photomultiplier voltage sensitivity of the read-out in terms of dose can be varied. For periodic check, there is an in-built stable green LED light source provided in the instrument. With good phosphor, standard deviations less than 5% in measured dose could be obtained (Thelmedor, Model 6000 TLD Reader, Instruction Manual, DRP, BARC).

3.3.6 STYROFOAM CUTTING DEVICE:

The Huestis Styro-former is the styrofoam-cutting machine (Fig.3.9) which consists of an electrically heated wire which pivots about a point simulating the source or x-ray target. The film, the styrofoam block and the wire apparatus are so adjusted
that the actual treatment geometry is obtained. The source point and the blocking tray are joined together by a calibrated tie rod. Once adjustments to a particular geometry of treatment has been made, the two components can be moved as a unit to any treatment position. The lower end of the wire traces the outline on the film. The heated wire will follow the pattern traced, producing a smooth, clean cut through the foam block. The block, with this area cut out, then becomes the pouring form used for casting a shielding block. The swivel mounting and spring loaded teflon tracing tip give the operator a complete maneuverability. The verification light system provided with this unit assures the accurate cutting in the styrofoam block (Data sheet SF794, Huesis Machine Corporation).