# Analysis of a linear accelerator

Nowadays patient with cancer are treated by radiation, surgery, chemotherapy or with a combination of these options. The radiotherapy treatment unit used to deliver radiation to cancerous cells and tissues is the linear accelerator, also known as linac.

The linear accelerator has been defined by Khan F. M. (2003) as a device that uses high-frequency electromagnetic waves to accelerate electrons, to high energies through a linear tube. The electron beam itself can be used for treating superficial toumors, or it can strike a target to produce x-rays for treating deep-seated toumors. The energy used for the radiotherapy treatment of deep situated tissues varies from 6-15 MV (photons) and the treatment of superficial toumors (less than 5cm deep) is between 6-20MeV. (Khan, 2003)

The purpose of this essay is to describe a linear accelerator, analyse its components in the stand and the gantry of the linac, and explain the principles of operation and then discuss why it is best situated to the task for which it was designed. Some advantages and disadvantages of the linac will also be included in the discussion part of the essay.

## Main body:

Figure 1: http://www. cerebromente. org. br/

As you can see from the schematic picture above, the major components of a linac are:

Klystron: source of microwave power

Electron gun: source of electrons.

Waveguide (feed and accelerating waveguide): microwaves travel through the feed waveguide and then to the accelerating waveguide, where electrons are accelerated from the electron gun.

Circulator: a device that prevents microwaves of being reflected back from the accelerator.

Cooling water system: cools the components of the linac.

Bending magnet: " A bending magnet is used to change the direction of the accelerated electron beam from horizontal to vertical." (Hendee et al, 2005)

X-ray target: electrons hit the target and produce x-rays.

Flattening filter: even out the intensity of the beam.

Ionisation chambers: they control the dose leaving the head of the linac.

Beam collimation: shape the radiation beam to a certain size

## Klystron:

There are two types of microwave power. The klystron and the magnetron. Magnetrons are used for lower energy linacs. In the high energy linear accelerator klystron is used. All modern linacs have klystrons. Both klystron and magnetron are special types of evacuated tubes that are used to produce microwave power to accelerate electrons. (Karzmark and Morton, 1998). " The tube requires a low-power radiofrequency oscillator to supply radiofrequency power to the first cavity called the buncher." (Hendee et al, 2005) In the bunching cavity, electrons produced from the electron gun, are bunched together to regulate their speed.

The microwave frequency is thousands times higher than ordinary radio wave frequency. For a linac to work, the microwave frequency needed is 3 billion cycles per second. (3000MHz) (Karzmark and Morton, 1998)

## Electron gun:

The electron gun is part of the klystron. Here, electrons are produced and then accelerated to radiofrequency cavities. The source of electrons is a directly heated filament made from tungsten, which will release electrons by thermionic emission. (Bomford, 2003) Tungsten is used because it is a good thermionic emitter with high atomic number, providing a good source of electrons. Klystrons usually have 3-5 cavities, used to bunch electrons together and increase microwave power amplification.

## Waveguide:

There are two different types of waveguides used in linacs. The first is the feed waveguide and the second is the accelerating waveguide. The first one connects the klystron to the main part of the linac. Sulphur hexafluoride (SF6) is used in the feed waveguide, to stop the arcing of electrons, caused by the microwaves that create strong electric fields.

A circulator is placed in the waveguide system, to prevent microwaves being reflected back.

Microwaves travel then to the accelerating waveguide. “ The accelerator guide of a linac requires a high vacuum to prevent power loss and electrical arcing, caused by interactions of electrons with gas molecules.”(Cook, 1998)The acceleration of electrons takes place here. The accelerator waveguide bunch and accelerate the electrons with the microwaves.

Electrons travel with a high velocity to almost the speed of light. (98% of speed of light) Microwaves travel to the speed of light, so irises are used to slow them down, so that electrons can keep up with the microwaves and be accelerated.

There are two types of accelerator waveguide: the travelling and the standing waveguide. The difference between the standing and the travelling wave accelerators is the design of the accelerator waveguide. In the travelling wave accelerator, electrons travel towards the machine and microwaves are absorbed, but in the standing wave accelerator microwaves are reflected back upon themselves. The standing wave accelerator is the main type used in medical linear accelerators.

## Bending magnet:

The electron beam leaving from the accelerator waveguide continues through the bending magnet. This is used to change the direction of the electron beam, to exit through the treatment head. The bending magnet deflects the beam in a loop of 270o, or 90o. The most common degree of bending magnet used in linacs is the 270o achromatic magnet. The important property of this magnet is that the electrons are brought together despite the difference in energies. They are brought back together to the same position, angle, and beam cross section at the target, as they were when they left the accelerator waveguide.

## X-rays target:

The target is made of tungsten because of its high atomic number. When electrons, with their high speed, hit the target, made up from a high atomic number material, they undergo rapid deceleration. This sudden loss of energy results in the formation of x-rays and photons. “ To maximise the X-ray beam intensity, the transmission target will be thick enough to stop all the electrons bombarding it but thin enough to minimise the self absorption.”( Bomford, 2003)

In order to switch from photon to electron therapy, the target is removed to allow the electron stream to continue into the head of the machine.

## Flattening filter:

In order to make the beam intensity uniform across the field a flattening filter is used. It is usually made of lead, although tungsten, uranium, steel, aluminium, or a combination has also been used or suggested. The flattening filter absorbs more photons from the centre of the beam and fewer from the periphery of the beam.

## Ionisation chambers:

Ionisation champers measure the amount of radiation leaving the machine, quantified in units – Monitor units. Every linac has two ionisation chambers for safety reasons. The ionisation is a round, flat structure, filled with gas, divided into a number of segments, where each segment contains electrodes. When radiation passes through the gas, it is then ionised creating a high charged density that is controlled by the electrodes. The treatment terminates when the readings from the electrodes have reached a pre-set M. U value.

# Collimation:

A primary collimator limits the maximum field size for x-ray therapy (40 x 40cm). It ensures that x-rays leaving the target leave in a forward direction in order to minimise radiation leakage through the head.

The treatment field size is defined by the secondary collimator. This collimator reduces the transmission penumbra, since radiation must travel through the entire collimator thickness. It consists of four thick metal blocks, called jaws. There are two pairs of jaws, upper and lower jaws. With the use of asymmetric jaws, by moving each jaw individually, asymmetric field sizes can be produced. Half beam blocking can also be enabling. Different intensity patterns can be produced, from the standard flat beam profile, by moving during treatment. Multi-leaf collimators are “ finger like projections”, 1cm thick. These fingers like projections move independently in order to form the field shape more closely to the shape of the planning target volume. By using MLC’s, less radiation is given to normal tissues.

# Discussion:

From the introduction of this essay, the definition of the linac was given. A linac is a high voltage machine, used for the treatment of cancerous cells and tissues. With the structure of a linac this is achieved. By radiating cancerous tissues, with daily radiation treatment, cancerous tissues can be destroyed and then replaced by normal tissues.

Every component in the linac is carefully selected for the function for which it is designed. First of all, the klystron is used to produce microwaves, because it is better than a magnetron that is used for lower energy linear accelerators. Because linear accelerators have higher energy beam, klystron are used for production of x-rays.

Continuing to the electron gun, tungsten wire or filament is used, because of its high melting point, high atomic number, and it is ductile. With this features tungsten is a good thermionic emitter, is a good source of electrons and can be easily shaped into spiral, in order to create a larger surface area for the electrons to be emitted.

In the feed waveguide Sulphur hexafluoride (SF6) is placed with the intention of stopping the arcing of electrons. At the end of the waveguide a circulator is placed so as microwaves cannot be reflected back.

As we move on to the accelerating waveguide, and the standing wave accelerator used in linacs, we can see why the standing wave accelerator is used. " The backward travelling wave interferes with the forward travelling wave, alternatively constructively and destructively. The resulting standing wave has a magnitude of approximately double that of the travelling wave, and the peak intensity travels along the waveguide at the phase velocity of the travelling wave."(Knapp et al, 1968)

Following the waveguide is the bending magnet. Here we have the achromatic magnet where its main task is to change the direction of the electrons, but more important to bring the electrons together despite the difference in energies.

A flattening filter is used to make the beam even from the central axis to its peripheral edges, to have homogenous distribution of the dose.

Ionisation chambers are essential in a linac. They monitor the dose leaving the treatment head, so that the linear accelerator knows when to end the treatment.

Collimation in a linear accelerator is necessary. Without the primary and secondary radiation a linac wouldn’t be as suitable for the task for which it was designed. The field size and shape is vital in order to radiate only the cancerous tissues and not normal tissues. Nowadays with the advances of technology and the use not only of MLC’s, but also IMRT and IGRT, survival rates of cancer have increased.

Last but not least, a linear accelerator can treat a patient with different energy modalities. By removing the target, the electron stream can continue into the head of the machine and then be used for the treatment of superficial toumors. By leaving the target, photons are produced to treat deep-situated toumors.

Nowadays most linacs have virtual wedges, compared to some decades ago, where there where only manual wedges. Now radiographers with the use of virtual wedges don’t have to concern about manual handling, as they don’t have to do anything.

I believe that linear accelerators are not perfect. Linacs are extremely expensive to buy, so poor countries don’t have the opportunity to treat their patients from cancer. It is hard to keep up with the advances of technology, as everything is very expensive to buy, and only wealthy countries can buy the latest equipment. A disadvantage of switching from photon to electron modalities is that applicators and blocks are used to direct the electrons and shape the beam. Applicators are very heavy. Blocks are made of lead which may cause lead poisoning if they are not handled with care. The only disadvantage with MLC's is that when conforming the beam shape to the PTV, some radiation will be leaking, even when using the tongue and groove effect. Last but not least the linacs to work efficiently they need daily quality assurance tests and maintenance from physicists.

## Conclusion:

Linear accelerator is the main treatment unit used for the treatment of abnormal tissues. With its precise position of the beam, shaped differently for every patient individually, it certainly is the best machine for the treatment of cancer.

A linac uses microwaves to accelerate electrons and then hit the target where x-rays are produced. This x-rays are collected and then form the shape of the beam. Nowadays with the rapid advances of technology, linacs in a few years time will be even more efficient than today.

Definitely linear accelerators are best suited for the task for which they were designed. All the components of a linear accelerator are carefully selected for its needs. From the smallest to the bigger parts of the linac, are designed for the best outcome.

## References:

BOMFORD, C. K., 2003. Megavoltage beam generators. In: C. K BOMFORD and I. H KUNKLER, ed. Walter and Miller's Textbook of Radiotherapy. London: Churchill Livingstone, Pages 162-183.

COOK, M., 1998. X-Ray Production. In: A. DUXBURY and P. CHERRY, ed. Practical Radiotherapy Physics and Equipment. London: GMM, Pages 21-26.

HENDEE W. R., IBBOTT G. S. and HENDEE E. G., 2005. Radiation Therapy Physics. 3rd ed. Hoboken, New Jersey: Wiley-Liss.

KARZMARK, C. J and MORTON, R., 1998. A Primer on Theory and Operation of Linear Accelerators in Radiotherapy. 2nd ed. Madison, Wisconsin: Medical Physics Publishing.

KHAN M. F., 2003. The Physics of Radiation Therapy. 3rd ed. Philadelphia: Lippincott Williams and Wilkins.

KNAPP, E. A., KNAPP, B. C. and POTTER I. M., 1968. Standing Wave High Energy Linear Accelerator Structures. In: HENDEE W. R., IBBOTT G. S. and HENDEE E. G., 2005. Radiation Therapy Physics. 3rd ed. Hoboken, New Jersey: Wiley-Liss.