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REVIEW OF MEDICAL ACCELERATOR DEVELOPMENT AT SAMEER, INDIA*

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Abstract

At Medical Electronics Division of SAMEER, R&D for development of a 4 MeV energy electron linac for Cancer therapy was taken up in the late '80s. An "S" band standing wave side coupled structure operating at π/2 mode was developed for electron acceleration. The linac was integrated with other subsystems in collaboration with CSIO and PGIMER and first machine was commissioned at PGI, Chandigarh in the year 1990. Thereafter, a lot of modifications like energy, dose rate, iso-center height etc. were made in the system and later 4 more machines were commissioned in hospitals for treatment. More than 150,000 patients have been treated using SAMEER's 6 MeV oncology system. Subsequently development of dual mode and variable energy electron and photon output machine was undertaken. Two photon energies of 6 and 15 MV and multiple electron energies starting from 6 to 18 MeV for treatment was offered from the linac. The electron energy variation was done using plunger mechanism in the side coupling cavity. This linac was successfully baked and RF tested for various parameters. This paper describes the experimental parameters achieved for both low energy and high energy dual mode linac.

INTRODUCTION

Radiation therapy (RT) or radiotherapy is being used for over a century now for treatment of various types of cancers. The high energy x-rays from linac or gamma rays from radioactive sources are used to treat deeply seated tumours by altering the growth and division of cancerous cells. With the discovery of high power RF sources during WW-II, compact high energy linacs were developed for industrial as well as medical purposes. Linacs delivering mega volt electron beams were developed which in turn provided deeply penetrating X-rays. It was predicted that by 2020 there will be 1.6 million cancer patients in India and by 2040 numbers will increase to 2 million [1]. Number of radiotherapy machines per million populations is approximately 5 for western countries. This number reduces to 1 machine per million populations for developing nations and for African countries the number falls to less than 1 [2]. 82% of worldwide radiotherapy machines deliver 6 MeV energy and is used to treat most types of cancers. Share of higher energy linacs providing both photons and electrons is 64%.

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BACKGROUND OF SAMEER

SAMEER is an off shoot of Tata Institute of Fundamental Research (TIFR) was established in the year 1984 as an autonomous research and development laboratory under then Department of Electronics. Currently, it is an autonomous institution under Ministry of electronics and information technology (MeitY), Government of India. SAMEER has 6 centres with head office at Mumbai. At Medical Electronics Division, R&D for development of a 4 MeV energy electron linac for Cancer therapy was taken up in late '80s. An "S" band side coupled linear accelerator operating at π/2 mode was developed for electron acceleration. The linac was integrated with other subsystems in collaboration with CSIO and PGIMER and commissioned at PGI, Chandigarh in the year 1991. The machine was called Jeevan Jyoti-I shown in Fig. 1 [3].

Figure 1: Jeevan Jyoti: India's First Indigenous Radiotherapy machine.

Subsequently, three more machines were installed at CCWH, Thakurpukur, Kolkata, GMCH Chandigarh and at MGIMS, Wardha. Linac delivered 200 Rads/min at 1 m at 4 MeV electron energy. The machine delivered more than 36,000 exposures/doses to the patients from 1991 till 2000 when it was decommissioned. The other two machines at CCWH, Kolkata (1996 to 2006) and MGIMS, Wardha (2006 to 2013) delivered more than 18,000 and 72,000 exposures respectively. Jeevan Jyoti machines met the requirement of oncologists though they were basic machines.

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Later under the Jai Vigyan (JV) initiative of Government of India, six radiotherapy units were developed and commissioned in hospitals. The specifications of the Siddhartha Radiation Oncology machine are given in Table 1. JV machines, called Siddhartha cumulatively treated more than 150,000 patients at various centres till date shown in Fig. 2. Treatment using these machines is still ongoing at IIHNO, Indore and ACF Hospital, Amravati. The percentage depth dose curve of one such machine is shown in Fig. 3. These machines were type approved by Atomic Energy Regulatory Board (AERB).

Table 1: 6 MeV Oncology Machine Parameters

Parameter	Value
Energy	6 MeV
Dose rate	240 Rads/min at 1 m
Field size	0x0 to 35x35 cm^2 with sharp corners
Flatness	±5% at average dose of 80%
Iso-center height	134 cm

Figure 2: Siddharth- Radiation oncology machine.

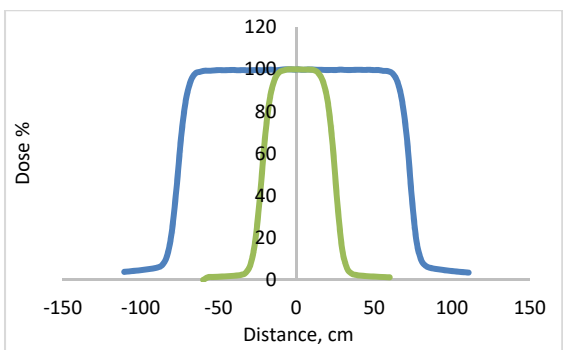

Figure 3: Percentage depth dose curve, (blue) 15x15 cm^2, (green) 5x5 cm^2.

LINAC AND ITS SUBSYSTEMS

SAMEER's 6 MeV linac is an S-band, bi-periodic structure, operating at π/2 mode at 2.998 GHz frequency as shown in Fig. 4. Electrons are produced in a Pierce type electron gun consisting of imported dispenser type cathode with emission current density of 1 A/cm^2. The focussed pulsed beam is injected with an energy of 20 keV from the gun. The accelerating structure is powered in pulsed mode with microwaves of 2.6 MW. The dominant mode responsible for the acceleration in the RF cavities is TM_{010}. Linac has a buncher and accelerating sections. Buncher section cavities are shorter in length to help in forming bunches of electrons with small relativistic β. Above 1 MeV energy electrons become relativistic and therefore beta becomes nearly constant. At 2.998 GHz frequency, the wavelength (λ) is 10 cm therefore the accelerating cavities length is fixed. The acceleration gradient achieved in the linac is 30 MV/m. Therefore, in accelerating structure length of 30 cms, 6 MeV energy is achieved. Electron after exit from accelerating cells are bombarded on the Tungsten target to produce bremsstrahlung X rays. The generated X-rays are of a continuous spectrum with maximum energy as the energy of electrons. Ultra-high vacuum ~ 10^{-10} mbar is maintained inside the linac to minimize scattering of electrons. The high power microwave side from RF source to the entrance of linac needs a proper insulating gas like sulphur hexafluoride (SF_6) to avoid breakdown issues.

Figure 4: 6 MeV linac.

Hence to separate the high pressure SF_6 region from the ultra-high vacuum side of linac, an RF window made in house of 99.7% pure alumina was designed and integrated with linac. RF window is so designed that it transmits microwaves across it without much loss while maintaining high pressure on one side and vacuum on other side. Water cooling is provided to the entire structure to take care of heat dissipated in the cavities. During the operation with the insertion of RF power, residual outgassing takes place. Therefore, a small sputter ion pump with 8 litres per second capacity is added to the structure. It also indicates the vacuum level inside the linac during operation. The 6 MeV linac is mounted vertically on the gantry head along with shields and collimator assemblies.

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After successful demonstration of parameters and patient treatment at various locations, it was decided to enhance the technology and introduce the possibility to achieve dual photon energies of 6 & 15 MV from the same linac. Besides, the linac must also deliver multiple electron energies 6 to 18 MeV for treatment. The parameters targeted to achieve in the high energy linac is given in Table 2.

Table 2: Dual Mode System Parameters

Parameter	Value
Particle	Electrons and photons
Photons energy	6 & 15 MV
Electrons energy	6, 8, 10, 12, 14, 16, 18 MeV
Dose rate	500 Rads /min at 1 m
Field size	0x0 to 35x35 cm^2 with sharp corners
Flatness	±3% at average dose of 80%
Iso-center height	130 cm

To vary the energy, it was decided to use detuning plunger in the coupling cavity in the acceleration section shown in Fig. 5. When plunger is inserted in the cavity, it detunes the coupling cavity and RF power is not coupled to the adjacent cavity. Thus providing only a section of length for the acceleration of electrons. Dual mode linac sub assemblies before integration to the linac is shown in Fig. 5. The measured parameters of the linac in detuned and tuned positions is given in Table 3. The main parts of the beam line assembly are gridded electron gun, main accelerating structure, a 270º achromatic bending magnet, an electron exit window, RF window and retractable X-ray target assembly.

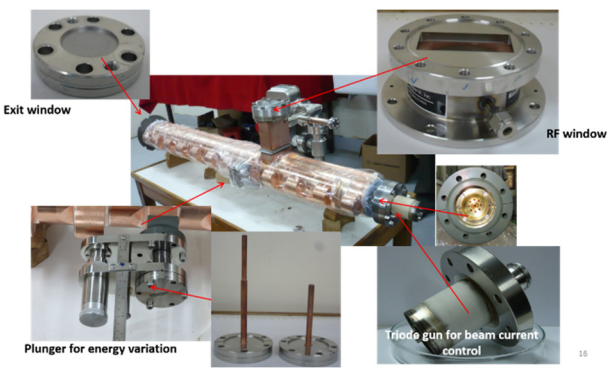

Figure 5: Dual mode linac sub assemblies.

Table 3: Dual Mode Linac Measured Parameters

Parameter	Tuned	Detuned
π/2 frequency, MHz	2996.56	2996.68
VSWR	1.23	3.12
Coupling coefficient, %	0.026	
Shunt impedance, MΩ/m	89	96
Leak rate, mbar-l/sec	$2x10^{-10}$	
Vacuum, mbar	$8.1x10^{-8}$	

A prototype of dual-energy linac is developed and tested at SAMEER [4]. The energy variation experiments and dose measurements both in electron and photon mode is carried out. Apart from this other major sub system are microwave system, water cooling system, control console, gantry, optics system, beam handling system, dosimetry and patient couch assembly. An integrated treatment planning system and multi leaf collimator is also a part of this machine. The linac is successfully assembled and low power measurement is complete. The beam bending chamber is individually tested with an ion source. The main feature of this development is to produce clinically acceptable quality electron beam and photon beam conforming to all the specifications desired by medical doctors viz. beam energy, dose uniformity, flatness and symmetry, etc. This linac will suffice the need for oncologists to have multiple energies as well as both photons and electrons at the same location.

SUMMARY

Medical accelerators giving electrons and photons are developed at SAMEER and treatment was given to the patients using 6 MeV linac based radiotherapy system. The 6 MeV oncology machine conformed to all the medical parameters of flatness and symmetry. Patients are still treated at hospitals using these machines. Dual mode linac parameters of dose and energy are demonstrated. Other parameter measurements are ongoing as of now. With the development of these machines SAMEER has established the basic technology required for cancer treatment in India.

REFERENCES

[1] National Cancer Registry, http://www.ncdirindia.org/NCRP/Annual_Reports.aspx

[2] DiRAC, http://www.ncdirindia.org/NCRP/

[3] T. S. Dixit *et al.*, "Development of a prototype 15 MeV Electron Linac", in *Proc. 1st Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, May 2010, paper MOPEA050, pp. 187-189.

[4] T. Dixit *et al.*, "Dual mode medical linac development at SAMEER", in *Proc. of the 7th Indian Particle Accelerator Conference (InPAC'15)*, Mumbai, India, Dec. 2015, paper ID-195, p. 520.