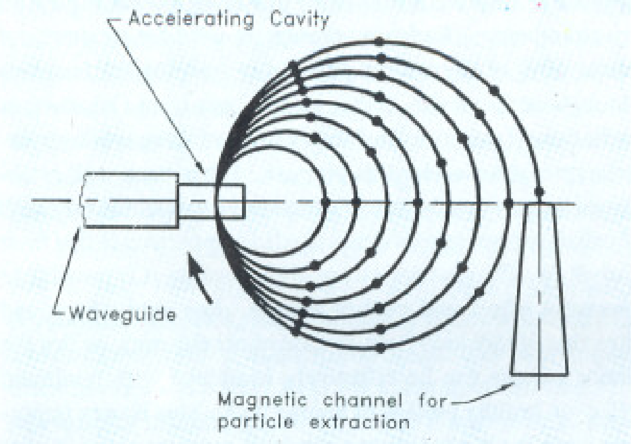
MICROTRONS FOR RESEARCH, MEDICINE AND INDUSTRY

Microtron is an electron accelerator capable of accelerating electrons in the energy range of few tens of MeV. It is a powerful tool for research, medical and industrial applications. It is also used as an injector to higher energy electron accelerators and as well as Free Electron Laser. One of the most important applications of microtron is for treatment of cancer patients by radiotherapy. It is also used for x-ray radiography of metallic and nonmetallic components in nuclear power, ship building, armament and space industries. Compared to other electron accelerators such as betatron and linear accelerator, microtron has a simple construction, lower cost and excellent beam qualities. Considering its vast potential, a programme for design and development of microtrons was taken up at Centre for Advanced Technology and two microtrons, one with 20 MeV beam energy, 30 mA current and second 8/12 MeV energy, 50 mA current were developed.

The basic principle of microtron can be explained with the help of figure given below. Charged particles are accelerated by an alternating electric field of constant frequency in a steady and uniform magnetic field. The electrons move in circular orbits, such that all orbits have a common tangent at the axis of RF cavity. The synchronism of electrons with accelerating field is achieved by the fact that the orbit period of each succeeding orbit is longer than the former one by an integral number of periods of RF frequency. This principle of synchronism is applicable only for relativistic particles having almost same velocity independent of their energy. Therefore, the microtron is useful for acceleration of light particles like electrons or positrons, which become relativistic during the first orbit itself.



Principle of Microtron operation.

Microtron has only one RF cavity and electrons repeatedly pass through it and gain energy. As against this, in linear electron accelerator, several RF cavities are arranged in series and the electrons pass through them one after the other to gain energy. A 20 MeV linear electron accelerator will need about 50 RF cavities. It also needs much higher microwave power than a microtron. For example, a 20 MeV microtron for radiotherapy machine can be made by using a 2.0 MW magnetron whereas a 20 MeV linac will need a 5.0 MW klystron, the cost of which is 4 times higher than that of a 2.0 MW magnetron system. Further, the fabrication of components for microtron is relatively simpler while the accelerating structure of linac needs special manufacturing facilities. This is due to stringent mechanical tolerances on RF cavities and ultra high vacuum grade leak tightness on the accelerating structure. However, the maximum beam pulse current from a microtron is limited to typically lower than 100 mA. On the other hand, the linac can provide much higher electron beam pulse current. Microtrons are therefore advantageous for applications which require lower beam pulse current and better electron beam quality in terms of energy spread.

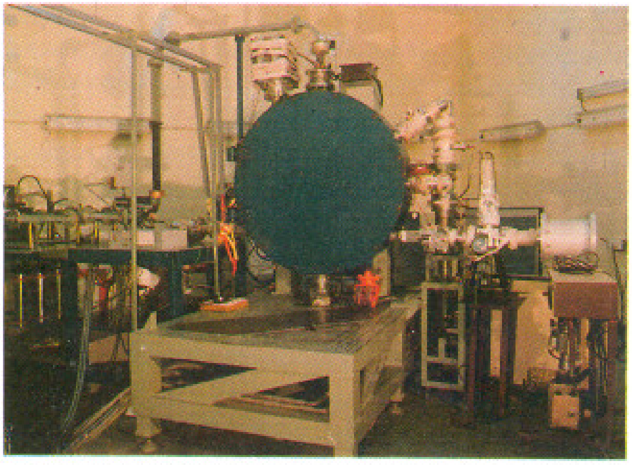
Two models of microtrons have been developed at CAT. Model 1 is a 20 MeV, 30 mA microtron suitable as an injector for high energy accelerators. One microtron of this model was made and installed at CAT and is being used as an injector to 700 MeV booster synchrotron, of Indus synchrotron radiation facility. It is working satisfactorily for last two and half years, its specifications are shown in table (page 6). It is also suitable for photon and neutron activation analyses and radiotherapy applications. Model 2 is a 8/12 MeV, 50 mA microtron suitable for studying interaction of radiation with matter, study of kinetics of chemical reactions, activation analyses, determination of gold in mineral samples, radiotherapy and industrial radiography. One microtron of this model with specifications as shown in table (page 6) has been made and supplied to Mangalore University for research and education purposes. The internal details of this microtron are shown in cover photograph. The RF cavity, beam extrac-

Microtrons developed at CAT

Parameters	Model 1	Model 2
Beam Energy	20 MeV	8/12 MeV
Energy spread	0.2% max	0.35% max
Pulse Current	30 mA	50 / 30 mA
Pulse duration	1 - 2 μsec	2.5 μsec max
Pulse repetition Rate	1 - 3 Hz	upto 250 Hz
Average Beam Power	-	250 W max
Beam size inside Microtron	3 mm x 5 mm	3 mm x 5mm
Number of orbits	22	14
Electromagnet diameter	1370 mm	740 mm
Mean pole gap	105 mm	98 mm
Weight of Electromagnet	2011 kg	550 kg
Magnetic field strength	1836 G	1285 / 1928 G
Microwave Source	Klystron	Magnetron
Power of Microwave Source	5.0 MW max	2.0 MW max
Operating frequency	2856 MHz	2998 MHz
Voltage in RF cavity	0.98 MV	0.67 / 1.0 MV

tion channel, field measuring probe and bottom pole of the magnet are visible in the photograph.

The main magnet assembly is shown in the photograph below. It produces a uniform magnetic field with uniformity better than 0.2% in a zone up to the last orbit. It also acts as a vacuum chamber. The RF cavity is one of the most important components of a microtron because under the influence of its electromagnetic field, the electrons are emitted, captured, accelerated and focused. It resonates in TM010 mode at nominal frequency in the range of S-band. An electron emitter is mounted in one of the walls of the RF cavity. Emission of electrons from the emitter is due to Schottky effect under the influence of RF electric field of the cavity. The electron emitter used is a cylindrical pin of 3 mm diameter and 3 mm length made of Lanthanum Hexaboride (LaB_6). Microwave system consists of a microwave source, a pulse modulator and a microwave transmission line. Pulse modulator provides high voltage pulses to the microwave source. Microwave power from the microwave source travels in a microwave transmission line at the end of which RF cavity is mounted.



Microtron, being used as an injector to synchrotron. The photograph shows main magnet (vacuum chamber), vacuum pumps and microwave transmission line along with other systems.

The beam extraction system consists of an extraction channel, correction rods, target, extraction mechanism and stepper motor drive. The energy of electron beam can be varied in a wide range by extracting the beam from different orbits. A microtron works under high vacuum condition with pressure in the range of 10^{-6} to 10^{-8} mbar. The life of electron emitter strongly depends upon the level of vacuum inside microtron. Poor vacuum reduces life of emitter drastically. Also high voltage (~ 700 to 1000 kV) in RF cavity can be maintained under high vacuum conditions only. Good vacuum is also required to prevent scattering of electrons with the air molecules. A turbomolecular pump and a sputter ion pump are used to achieve the required vacuum in microtron. A beam diagnostics system to monitor beam energy, energy spread, position, pulse current, pulse time structure and emittance can be provided with microtron. A personal computer based control system is used for operation and control. Various safety interlocks are provided for safety of equipments, systems and operating/ maintenance personnel. The microtron is a radiation producing machine and should be installed in a room with radiation shielding walls. Also, it should have very good ventilation.

To give an idea of the wide range of microtron applications and their benefits over other accelerators, we discuss few of its important applications. One of the most important applications of microtrons is for treatment of cancer patients by radiotherapy. Radiation therapy is used for treatment of about 60% of the cancer patients in oncological hospitals throughout the world. Either gamma rays from Cobalt-60 or radiations (electron and x-rays) from megavoltage accelerators are used for this purpose. It has been well established by now that the rate of success of treatment is very high if radiation from accelerator is used in comparison to that from Cobalt-60. The success rate is high, because it is possible to precisely adjust and control energy, dose rate, shape and direction of radiation field, in case of accelerators, so that the tumor volume can be effectively irradiated with minimum effect on healthy portion of human body. This is very important when the tumor is near a sensitive organ or gland. As per one study, the patients of bladder tumors treated under radiation therapy with Cobalt-60 gamma rays, yielded a five year survival rate of 14%, whereas for radiation therapy by x-rays from accelerators, raised it to 55%.

The radiotherapy machines based on both linear electron accelerators and microtrons, are available commercially in the world market. Maintenance and servicing costs of such machines are very high and in many developing countries, there is a lack of infrastructure to properly maintain these machines. The recommendations of the Advisory Group constituted by WHO, IAEA, UNIDO and PAHO also confirms that the radiotherapy machines based on linacs are quite expensive.

After assessing the requirements of radiotherapy machines in our country and considering the definite advantages of microtrons for this application, CAT has also taken up the development of radiotherapy machines based on 12 MeV and 20 MeV microtrons. The machine will consist of a microtron, a beam transport line, a treatment head, a gantry and a couch. Treatment head will have a provision for exposure of patient by electron beam as well as by photon beam. The maximum dose rate will be 5.0 Gy/min. The electron beam energy, the dose rate and size of radiation field will be adjustable in a wide range.

Microtrons are also used for production of Iodine-123. Use of Iodine-123 for diagnosis of disease in liver, thyroid gland, heart, etc. is well established. Nuclear reactions with protons, alpha particles and deutrons having energies from 10 to 100 MeV are used for production of Iodine-123. Accelerators providing such particle beams are quite expensive, therefore, the cost of production can be brought down drastically if microtron, which is very cheap, is used for producing Iodine-123. Due to lower capital cost such production facilities can be established at several centres in our country catering to the needs of various zones. For production of Iodine-123, enriched Xenon-124 target is bombarded with intense photon beam, generated by the electron beam of microtron. The gamma neutron (γ-n) reaction produces Xenon-123, which decays to Iodine-123. A team of scientists at JINR, Dubna, Russia has achieved Iodine-123 production rate of 20 mCi/hr by using 25 MeV, 20 mA microtron. As individual diagnostic dose range from 0.1 micro Ci (for thyroid gland) to 1.0 micro Ci (for heart, liver, etc) this rate of production is sufficient for diagnosis of few hundred patients per day after accounting for losses at various stages.

Electron accelerators are also widely used in nuclear power, ship building, armament and space industries in developing countries, for radiography of metallic and non-metallic components, where the thickness to be radiographed often reaches equivalent steel thickness upto 250 mm. If a radiography machine based on 12 MeV microtron is made, the exposure time needed for 250 mm thick steel will be less than 5.0 minutes as compared to that of 3.5 hrs. with Cobalt-60 camera.

Microtrons are also used for photon as well as neutron activation analysis. Photon activation analysis has application for determination of oxygen, nitrogen and carbon in high purity metals. Around 20 to 37 elements can be determined in soil and sediments by photon activation analysis. This method is based on photo excitation reaction using gamma photons with energy about 9.0 MeV. Sensitivity of determination of gold in ore samples by this method is 0.3 ppm.

It is possible to achieve neutron yield of 10^{12} n/sec by using a 20 MeV microtron. This neutron yield is very good for conducting neutron activation analysis and for neutron radiography.

Due to intrinsic low energy spread and emittance of electron beam from a microtron, it is considered to be a good candidate as a source of electron beam for construction of Free Electron Laser in far-infrared range. A FEL which will provide tunable radiation around 200 micrometer is being built at CAT by using 8 MeV, 100 mA microtron.

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