# ACCELERATOR FACILITIES AND RELATED RESEARCH PROGRAMMES AT UNIVERSITY OF PUNE

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*Abstract*

In the Department of Physics, University of Pune, Pune, a 200keV ion accelerator and a 6 to 8 MeV electron accelerators were developed using mostly indigenous components, and being used since 1980 onwards for research and teaching work.. The ion accelerator can provide gaseous ions such as hydrogen, deuterium, argon, etc over energy range 30keV to 200 keV at a current level of~150 microampere. The gaseous ions from this accelerator are used in research work related to ion irradiation, ion implantation, etc. Most of the time, this ion accelerator is used as a 14 MeV neutron generator involving D-T reaction. The 14 to 14.8 MeV neutrons with flux ~ $10^8$ n/cm$^2$-sec are used for research work in the fields of nuclear reactions, elemental analysis, etc.. The other accelerator facility is an electron accelerator called Race-Track Microtron, unique in the country. This accelerator can provide electrons over two energy ranges; 0.5 MeV to 1 MeV and 6 to 8 MeV. The electron beam is being used for different studies such as bremsstrahlung production, gamma-ray radiography, and radiation damage in semiconductor devices, polymers, & space quality materials. Recently, a new irradiation system has been developed to simulate space radiation environment. This system has facility to irradiate a sample with hydrogen ions of energies up to 50 keV, and electrons of energy up to 30 keV simultaneously under exposure of UV radiation. All these indigenously developed facilities have contributed significantly in the accelerator based research and teaching programmes. The 6.5 MeV electrons from the Race-Track Microtron were successfully used in tailoring the switching characteristics of a number of thyristors &diodes made by BHEL, Bangalore. Similarly, the 14 MeV neutrons have been used for the analysis of explosive class materials.

## INTRODUCTION

The University of Pune is the only university in the country where low energy electron and ion accelerators were developed around 1980. The main parts of the 200 KV ion accelerators, such as r.f. ion source, accelerating column, Cock-Croft Walton high voltage unit, isolation transformer, control system, vacuum chamber, etc. were fabricated in the university workshop. In this manner the ion accelerator was made using indigenously available components and materials. The other accelerator developed is an electron accelerator called Race-Track Microtron.

In general, the Microtron falls in the category of re-circulating accelerators. There are two types of Microtrons; one is conventional type and the other is Race-Track type. The first Microtron designed was of conventional type, proposed by Veksler [1]. For the first time the development of conventional Microtron took place in Canada [2]. However, later on a number of conventional Microtron were made and operated in different countries such as U.K., USSR, and Sweden. The concept of "Race-Track Microtron" was proposed by Moroz and Roberts [3,4], but the approach was different. The first practical Race-Track Microtron was designed and built by Brannen and Froelich [5] in Canada. Later on several different energies, Race-Track Microtrons were developed during the last fifty years. So far the useful maximum electron energy achieved form a Race-Track Microtron is close to 200 MeV.

In India, there are three Microtrons in operation; two conventional types and one Race-Track type. The two conventional microtrons are in operation, one each at RRCAT, Indore and Mangalore University. The third Microtron is of Race-Track type, and in operation at University of Pune, since 1980.

## ACCELERATOR FACILITIES AT UNIVERSITY OF PUNE

### *(A) 200 keV ion accelerators*

The 200 keV ion accelerator is installed in a shield room. The main parts of the 200 keV ion accelerator are (i) rf ion source, (ii) metallic dome to house the rf ion source and power supplies (iii) 200 kV dc power supply, Cock-Croft Walton type (iv) accelerating column, (v) rotary diffusion vacuum system, (vi) current Integrator and (vii) Control panel.

A photograph of the 200 keV ion accelerator is shown in Figure 1. The rf ion source along with its power supplies and the r.f. oscillator are mounted in the metallic dome. The metallic dome is supported on four polyethylene rigid pipes, at a height of ~ 1500 mm above the ground level. One end of the ten stage accelerating column rests in the dome whereas its other end is fitted to a T-shaped SS chamber. The bottom side of this chamber is connected to the vacuum system. The height of the T-shaped chamber was adjusted in such a way that the accelerating column remained parallel to ground surface. The other end of the T-shaped chamber is connected to a 200 mm long stainless steel tube carrying the target holder, with facilities of water cooling.

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Figure 1: A view of the 200 keV Ion accelerator/14 MeV neutron Generator.

The rf ion source is mounted at the other end of the accelerating column, and supported in the metallic dome. Operational parameters of the ion source and the accelerating voltage are controlled from a central control system housed in an adjacent room. The operational parameters of the machine such as accelerating voltage, magnet field in the ion source, ion extraction voltage, rf power, gas leak rate, ion current on the target, vacuum level, etc. are displaced on the respective digital meters mounted on the control system.

The ion beam diameter on the sample mounted in the target holder is close to ~ 3 mm. An electro-magnetic system is used to scan the ion beam on the sample covering an area ~ 12 mm X 12 mm. Ions of hydrogen, deuterium, nitrogen and argon have been used for research work related to ion implantation and irradiation. The ion current can be varied from 5 μA to 120 μA where as the accelerator voltage can be varied from 50 KV to 200 KV.

## *(B) 14 MEV Neutron generator*

The 200 keV ion accelerator is also being used for producing 14 MeV neutrons [6]. For this work, deuterium gas is fed in to the rf ion source. In addition, a tritium target of strength ~ 8 Curies is mounted in the target holder. The 14 MeV neutrons are produced through the following nuclear reaction

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17\ MeV\ (Q - value)$$

A sample is irradiated with neutron under atmospheric conditions. This reaction is induced by bombarding 130 keV to 200 keV deuterium ions on the tritium target. The deuterium current on the target can be varied form 50 μA to 150 μA. The sample for the neutron irradiation is transferred from the detector to the irradiation head and back by the pneumatic transfer system. For neutron activation analysis work, the complete cycle of activation is divided into four periods; (i) sample irradiation, (ii) cooling period to reduce the γ-ray, (iii) γ-ray activity measurement and (iv) waiting to reduce build up effects.

The control panel, gamma-ray detector, multichannel analyzer, pneumatic transfer system, etc., are kept in a room adjoining to the neutron generator room. In this manner, all the operations of the 14 MeV neutron generators are made remotely. A view of the control system of the ion accelerator/14 MeV neutron Generator is shown in Figure 2 and the respective specifications of the neutron generator is shown in Table 1.

Figure 2: Control panel of the ion accelerator/14 MeV neutron Generator.

Table 1: Specifications of the Neutron Generator

| | |
|---|---|
| Tritium target | 8 Ci |
| Deuterium ion energy | 30 keV – 200 keV |
| Ion current | Variable from 30 to 150 μA |
| Neutron energy | 14 MeV to 14.8 MeV(depends on the neutron angle of emission) |
| Neutron flux | ~$10^8$ n/$cm^2$ /sec |

## *(D) Race-Track Microtron*

In a Microtron, electrons gain energy while passing through the accelerating cavity. As the magnetic field between the magnet poles is uniform, the radius of the electron orbit increases according to the energy of the electrons.

In the conventional Microtron, circular magnet is used and cavity is kept between the magnet poles. However,in the Race-Track Microtron, instead of a uniform circular magnet, sector magnets are used .As a result, field free regions exist. There are several advantages in the use of sector magnets such as (i) the accelerating cavity is kept in the field free region that exist between the sectors, (ii) magnet gap is reduced thus considerable saving in magnetizing power and iron of magnet yoke, (iii) freedom in setting energy gain per pass through the cavity and (iv) compact size of the machine (v)the distance between the pole pieces can be varied in the direction perpendicular to the vertical symmetry plane of the accelerator. The electrons while passing through the cavity gain energy and after travelling through the magnetic field and field free region enter the cavity again and gain energy. To allow electron to enter the cavity at proper phase, the time $T_k$ required to traverse the K-th orbit should be

$$T_k=2\pi m_0.E_k/e.B+S_k/V_k=n_k\tau=a+Kb$$
$$S_k/\lambda=a-b.E_{inj}/\Delta E$$

Where $E_k$ is the total energy of electrons in the K-th orbit, $S_k$ is the total field free space, $V_k$ is the velocity of the electron in the K-th orbit and $n_k$ is an integral and $\tau$ is the period of the r.f. field in the cavity, $E_{inj}$ is the total injection energy, $\Delta E$ is energy gain per pass through the cavity and a and b are integers as defined earlier.

The Race-Track Microtron of the University of Pune has four $90^0$ sector magnets, two each in a magnet module [7,8]. The two magnet modules are placed inside the stainless steel chamber. Each module is thus made of two $90^0$ sector magnets aligned in the horizontal plane. The gap between the magnet poles is 7 mm. Rectangular strips of mild steel, with holes at appropriate places are fitted between the sectors of each module to act as the magnetic shield. The top and bottom flanges of the chamber are made of mild steel to provide magnetic contact between the modules and the yoke fitted to complete the magnetic circuit. Two coils, each containing 8000 turns are fitted around the magnet yoke. The cavity, the electron gun and the Faraday cup are located in the field free region between the two magnet modules. The module situated on the side of the electron gun is cut at its other edge to accommodate a mild steel pipe for the beam extraction. The separation between the two magnet modules can be varied with motors.

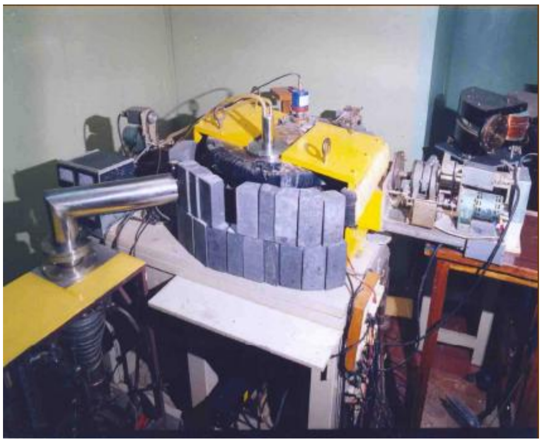

Figure 3: A view of the Race-Track Microtron.

A vacuum system is connected to the SS chamber to maintain a pressure of $10^{-6}$ torr. The entire microwave power system consist of ferrite isolator, phase shifter, tunable S-band magnetron and various S-band wave guide couplings. The cavity with 4.15 cm diameter and 3.43 cm length is made from OFHC copper and has a tuning frequency of 2780 MHz. The Q value and the shunt impedance are ~15300 and 1.56 M Ohms/cm respectively. The magnetron of 1 MW power (English Electric M 5083) is driven by a line type modulator. The pulse forming network provides ~ 2 µs pulse at a repetition rate of 50 pps, but can be varied up to 200 pps..

The electron gun is attached to the cavity and can be displaced externally. A small $90^0$ magnet bend the electrons into the cavity. In this Race-Track Microtron there are eight orbits, and the energy gain per pass through the cavity can be varied in the range~ 700 keV to 900 keV. In this manner the energy of the extracted electrons can be varied from around 6 to 8 MeV. The electron current ~70 mA can be extracted and incident on the target mounted out side the extraction port. A view of the Race-Track Microtron is shown in Figure 3.Similarly, the control panel of the Race track Microtron is shown in Figure 4. The operational and machine parameters of the Race-Track Microtron are shown in Table 2.

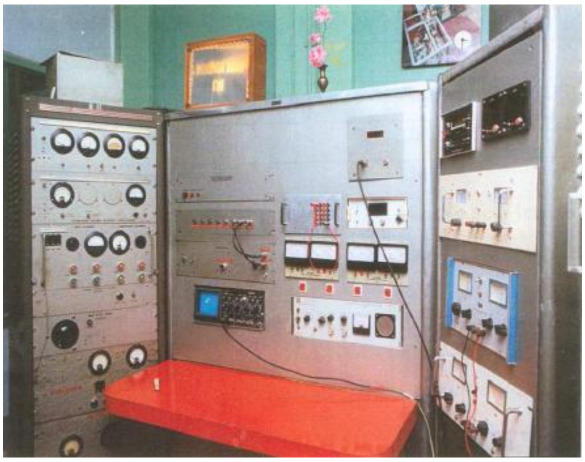

Figure 4: Control panel of Race-Track Microtron

Table 2: Operational and machine parameters of the Race-Track Microtron of the University of Pune

| | |
|---|---|
| Beam energy | 8 MeV(variable from 6.5 to 8 MeV) |
| Beam current | 1 mA |
| Beam emittance | 5 mm-miliradiance |
| Maximum pulse rate | 50 pps |
| Maximum pulse length | ~ 2 µ sec |
| Number of orbits | 8 |
| Beam extraction | 100 % |
| Microwave cavity | Right circular cylinder |
| RF mode | $TM_{010}$ |
| Operating frequency | 2780 MHz |
| Electron injection voltage | 17.6 kV |
| Magnetic field | 0.136 T |
| Magnet gap | 0.70 cm |
| Control field free space | 6.6 cm (variable) |

## *(C) Space Radiation environment facility*

The materials and components placed at the surface of the space-craft get exposed to low energy electrons and protons, in presence of UV radiation. To study the combined irradiation effects of electrons, ions and UV radiation on these materials used on the outer body on a space-craft is therefore of interest. To carry out these studies, a system consisting of electron source, ion source and a source of UV radiation has been developed in this laboratory. The radiation environment facility provides electrons of energy, varying from 500 eV to 20 KeV, protons of energy, varying from 5 keV to 50 keV and UV source of 100 W power with optical spectrum close to that of the sun spectrum. A sample can be therefore irradiated simultaneously with all these radiations simultaneously.

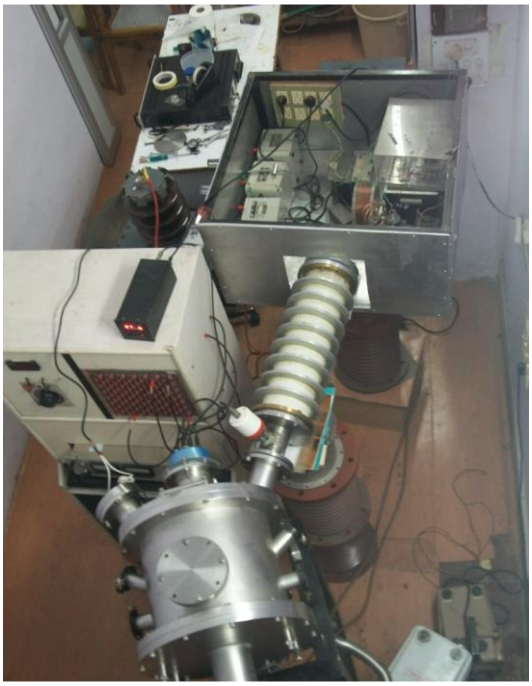

Figure 5: A view of the Radiation environment system.

## RESEARCH ACTIVITIES

### *(a) Using Race-Track Microtron*

- Radiation damage in semiconductor materials and devices.
- Tailoring of the switching characteristics of thyristors and diodes.
- Depth distribution of the defects induced in the surface and bulk region of the c-silicon by measuring the lifetime of minority carriers
- Irradiation effects of 1-6MeV electrons on the space quality (i) MOS devices (ii) electronic components (iii) polymers (iv)glass materials (v) functional oxides.
- Generation and characterization of bremsstrahlung radiation (e, $\gamma$) from some targets such as tungsten, Pb, Au, Ta, W,etc.
- Production of pulsed (2$\mu$ sec) neutrons through ($\gamma$,n) reaction.
- Radiation enhanced diffusion of elements such as boron, fluorine, silver, etc. in polymers and glass materials.
- Synthesis of gold, silver and CdS nanoparticles under 6.5MeV electron irradiation.

### *(b) Using Ion Accelerator and 14 MeV Neutron Generator*

- Ion irradiation and ion implantation
- Detection & analysis of elements, and applications to dating of archaeological objects, bones, etc.
- Measurement of cross sections for formation of short lived (1 to 100msec) radioisoptes.
- 14 MeV neutron induced fission of U-238 using glass detector and measurement of angular distribution of the fission fragments.
- Angular distribution of alpha-particles emitted in (n,$\alpha$) reactions with targets such as Al, Ni, etc.
- Analysis of explosive class materials
- Feasibility study of detection of explosives & landmines, using prompt gamma-ray analysis.

### *(c) Using Radiation environment system*

- Simultaneous irradiation of protons, electrons and UV on the thin coatings of optical materials, metal, insulators etc for space research and technology.
- Irradiation effects of low energy electrons on thin films/ coatings such as antireflection, reflective, thermal, transparent, conductive and solar absorbers.
- Synthesis of metal nanoparticles in polymer matrix using low energy electrons.

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