THE ENEA RACETRACK MICROTRON

L. Picardi, G.Giubileo, G.Messina, P.Raimondi, C. Ronsivalle, A.Vignati
Lab. Fisica e Ingegneria degli acceleratori
Dip Tecnologie di punta - ENEA CRE Frascati
ENEA p.o.box 65 00044 Frascati (Roma) ITALY

A variable energy (20-100 MeV) racetrack microtron has been constructed in the ENEA Accelerators Laboratories at Frascati.This machine designed to be used as a driver for a FEL source (20-30 MeV) in the infrared region, has a considerable interest also for other applications. It is composed of two 1 T magnets and a 5 MeV standing wave linear accelerator feeded by a 5 MW, 5 µs 3 GHz klystron, injection and extraction systems. In the following the various parts of the machine and the first beam measurements are described.

1.Introduction

The FEL experiments in the 10-30 um spectral region that are in progress at the ENEA laboratories at Frascati using a 20 MeV circular microtron [1] stimulated some years ago the construction of a racetrack microtron. In fact RTM beams show, as the circular microtron's ones, good emittance (2·10E-6 m rad at 20 MeV) and energy spread (10E-3), but, in addition, the cathode, placed outside of the magnetic field, allows a higher current, almost as the linac ones.

In addition other requests came in the last years from neutron spectroscopy CNR groups that needed 30 to 70 MeV beams, from INFN and University that were interested in the construction of a synchrotron X-rays source lithography dedicated and from ENEA and University for PET application development.

The ENEA RTM [2] (fig.1) consists of an injection system, a conventional side-coupled standing wave 5 MeV 2998 MHz linac, two 180° bending magnets (main magnets) with reverse-field magnets, extraction items and a vacuum system. It will have a maximum of 18 orbits and a minimum of 4. The energy gain per turn will range from 4 to 5.5 MeV and therefore we hope to be able to operate between 16 and 100 MeV continuously providing a beam at a fixed output.

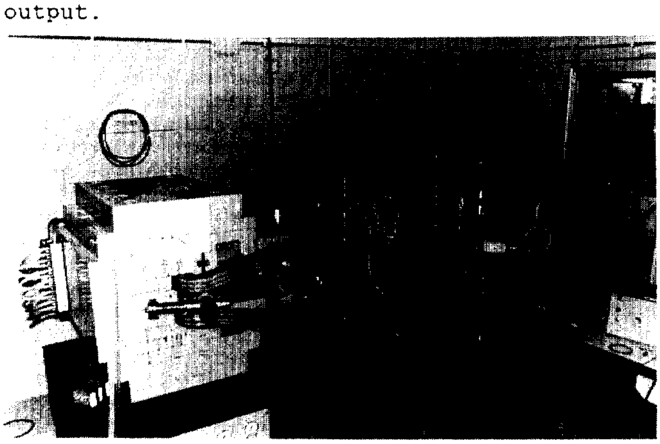

fig. 1

The status of the microtron is presented in the following sections.

2.Magnet system

The magnet system of the microtron is composed of two main magnets, first orbit recirculation magnets, injection and extraction magnets.

The two main magnets resemble each other the only difference being some cuts in the auxiliary poles made in order to place the radial correcting coils [3].

They are named "fixed magnet" and "movable magnet" because, during the operation of the accelerator, one of them is moved to fulfill the synchronism conditions.

Each magnet is constituted of several 5 cm. thick slabs of pure ARMCO iron bolted together. The 46 mm thick magnetic poles are separated from the rest of the magnet by 4 mm air gaps which act as a filter omogenizing the field in the main 20 mm gap. The main coils are made by 48 turns of 8 mm square copper conductor with a 5 mm bore for water cooling : the resistance of a coil is measured to be 42 mOhms at room temperature. The auxiliary coils are made of 72 turns of 5*2 mm copper wire each.

The computed magnetic field distribution in the median plane as obtained by POISCR [4] package is not different from that obtained from direct measurements. The magnetic measurements equipment consists of a Hall probe mounted on a support that can be moved by a computer controlled motor with a precision of 1 um. Measurements have been taken at 60,130,265,290 A in order to check the development of saturation in some parts of the magnet. The correspondance of the POISCR field shapes is quite good in all these tests, and the worsening of the field shape with intensity is within the allowable values of the computed orbits.

The first orbit recirculation magnets consist of a pair of small magnets by means of which the beam is reflected by one of the two main magnets after the first acceleration in the linac (fig.1). This scheme [5] solves the problem of the second orbit that otherwise would pass too close to the linac axis.

The injection magnet bends the 40 keV beam by 45° from the injection line to the linac axis and is cut in order to provide vertical and horizontal focusing. The deflection induced in the high energy transits of the beam is compensated by another similar magnet.

The extraction at present is not working:it will be performed deflecting the beam by means of magnets, one for each even orbit, placed outside the vacuum chamber in a 10 cm straight tube left free for this purpose. A 6° deflection will let the beam pass over the common axis and exit through a tube screened from fringing magnetic fields.

3.Vacuum chamber

The main vacuum chamber is connected to the chamber of the fixed magnet by 16 elliptic rigid pipes and to the movable magnet by 17 circular pipes equipped with bellows. The vacuum chamber of the fixed magnet is connected to the vacuum chamber of the linac by an elliptic section tube used for the first orbit recirculation. The linac vacuum chamber is mounted on a movable support controlled from the consolle.

The internal diameter of the pipes is 16 mm. Their position and their shapes have been determined from the computed orbits.

4.Injection

The injection system (fig.2) consists of an electron gun and related optics.The e-gun is composed of a dispenser M-type 10.48 mm. spherical cathode with its field forming electrode (supplied by the Elettronica SpA), a ceramic insulating support, a vacuum system that pumps directly in the cathode region by a 2 l/s ion pump.

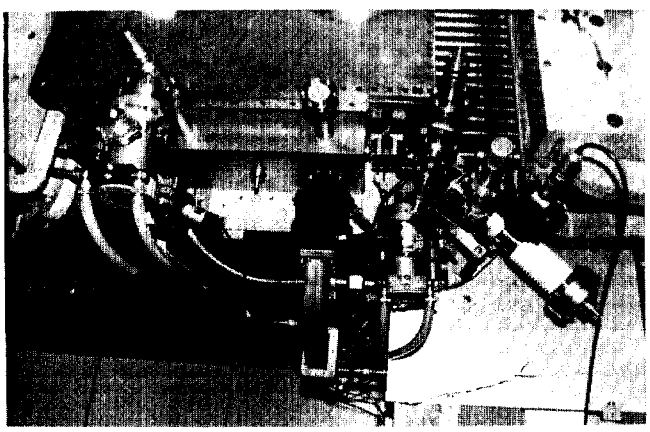

fig.2

The gun has been designed for 900 mA current at 40 kV by the SLAC Herrmannsfeldt code [6]. The computed beam appears to have a 4 mm diameter waist at 34 mm from the anode and to occupy a phase space area of 6.2 π mm*mrad.

The optics has been designed [7] in order to bring this beam with the best conditions focused at the linac entrance. Two solenoid lenses and a 45° bending magnet with cut edges are used.

From the mechanical point of view the gun is followed by a valve which is opened only if pressure is lower than 10E-7 torr and by a channel equipped with a vacuum section with a 50 l/s turbo pump in order to fix a pressure gradient with the rest of the accelerator where pressure is not better than 5·10E-7.

To check the assembly accuracy we did some radiographies to the gun from two different axes with a 5 MeV radiographic linac in operation in our laboratory without noting any asymmetry.

5.Linac system

The accelerating device is a π/2 mode biperiodic side coupled standing wave linear accelerator. The structure is symmetric with seven full cells and a half resonator at each end. Such a construction shortens the distance between the first and the second gap centers by about a quarter of a full gap width (5 cm) increasing the phase acceptance at low (30-50 kV) injection energy and simplifies the tuning procedures.

The shape of the accelerating cavities has been designed for a high shunt impedance with the help of OSCAR2D code[8]. In the table below the computed and measured linac parameters are listed.

Linac parameter	computed	measured
Frequency (MHz)	2998.	2998.
Shunt imp.(MΩ/m)	103.	80.
Qo	16912.	13000.
Coupling coeff. to the waveguide		3.5
ko,first nei.coupl.coeff.		4%
k1,acc.cav.coupl.coeff.		-.2%

The OFHC cert. grade copper cavities are machined on a numerical controlled lathe; every cavity is composed of two semi-cavities and each accelerating semi-cavity is machined in the same copper piece with a coupling semi-cavity . The measured differences between two accelerating semi-cavities are of the order of 1 MHz only after machining.Fine tuning has been achieved after brazing by tuning screws fitted in the structure.

The linear accelerator is contained in its own stainless steel vacuum envelope (fig.2), separated from the main vacuum chamber and pumped by a 50 l/s turbo pump.

The external dimensions of the linac vacuum chamber are 46.5*19*10 cm ,the encumbrance between the external wall and the axis in direction of the first recirculating orbit is 4.4 cm.

During the operation the RF power is supplied by the THOMSON TH2066 5 MW , 5 us klystron powered by a line type modulator, but, due to RF circuit losses only less than 4 MW are available.

6.Orbits computations

Computations of particle dynamics were performed by the program RCTRAK [9] kindly offered by the author M.Sedlacek and by him and ourselves adapted to our machine.

The simulation of the electron orbits has been done for a machine without allignment errors and without correcting coils.

The integration uses given electric field distribution along the axis of the linac and magnetic field distribution in the median plane. The electric field values were obtained by a Fourier expansion fitting measured values while magnetic field distribution was obtained by POISCR data by a sum of 5 Enge formulas in which the values of the coefficients were optimized by a least-square fit [10]. The computations have been made in order to optimize the machine parameters for the maximum phase acceptance.

With a gain of 5 MeV per orbit we

obtained the maximum capture efficiency with the following parameters:

distance between magnets........124.4 cm.
ratio between the contrapole
and main pole field............ 12.86%
magnetic field in the
recirculation magnets...........400 gauss
distance between the linac
center and the fixed magnet.....59.4 cm.

In order to evaluate the beam characteristics like emittance, energy spread and microbunch lenght, accurate calculations were performed using PARMELA code for the injection channel where space charge effects are relevant and using its output in RCTRAK. From these calculations a poor radial focusing results as can be seen in fig.3 where horizontal and vertical envelopes are compared at two different points of the machine at various orbits. This reflects directly on high beam losses expecially in the first two complete orbits. In the following table the losses going through the machine are shown, taking the injection current equal to 1:

Injection	1.
After the 1st linac transit	.43
After the first orbit reversal	.24
After the 2nd linac transit	.22
After the 4th linac transit	.13
After the 10th linac transit	.11

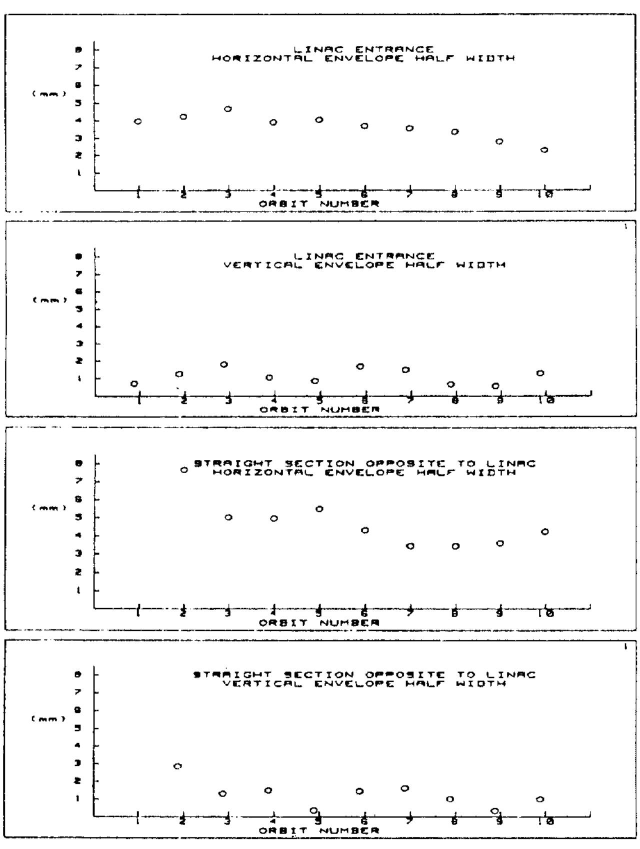

fig.3

We think that it will be possible to improve the overall acceptance by adding suitable focusing items and on the linac axis on the various orbits. Anyway in the present conditions,the calculated beam characteristics (fwhm) are listed in the table below at 10, 20, 50 MeV:

	εx mm mrad	εy mm mrad	δE/E %	δΦ °RF
10 MeV	2.8 π	.5 π	4	6
20 MeV	1.7 π	.2 π	2	10
50 MeV	.2 π	.08π	.7	16

7.Beam measurements

The electron beam tests have been decided in order to check the different parts of the machine. First of all we tested the gun and the injection channel checking that 800 mA were obtained at the entrance of the linac. Thereafter we tested the first passage through the linac, getting 340 mA of current at maximum klystron power with a maximum energy of 5.5 MeV.

Afterwards the recirculation of the beam in the linac i.e. the first orbit reversal has been tested producing a beam of 160 mA at 10.1 MeV comparable with the 177 mA predicted value.

Moving the linac with respect to the fixed magnet produced a variable energy beam between 1.8 and 11.1 MeV, energy measurements having been taken by range measurements in aluminum.

Finally the first three orbits were tested getting 140 mA at 10 MeV, and 90 mA at 15 MeV.

8.Conclusions

The ENEA 20-100 MeV racetrack microtron is working. First successful tests have been performed.

References

1) U. Bizzarri et al., Nucl. Instr. and Meth. A250 (1986) 254

2) L. Picardi, C.Ronsivalle, The ENEA Race Track Microtron: design criteria and status, RT/TIB/89/34 to be published in Nuovo Cimento D.

3) S. Rosander, M. Sedlacek, O. Wernholm, Nucl. Inst. and Meth. 204 (1982) 1

4) C. Iselin, The CERN-POISSON program package, CERN Computer Center, Program Library

5) M. Eriksson, Nucl. Inst. and Meth. 196 (1982) 331-340

6) W.B. Herrmannsfeldt, Electron trajectory program, SLAC-266,UC-28

7) M. Catena, C. Ronsivalle, ENEA internal report RTI/TIB(88)-38

8) P. Fernandez, R. Parodi, 1986 Linear Accelerator Conference, pp.330,332

9) M. Sedlacek, "RCTRAK, a computer program for simulation of linear accelerators and racetrack microtrons", Internal Report, Dept. of El. Physics, RIT, Stockholm

10) L. Picardi, P. Raimondi, C. Ronsivalle, ENEA internal report.