CURRENT STATUS OF THE 12 MeV UPC RACE-TRACK MICROTRON*

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Abstract

We report on the current status of the technical design and results of tests of some components of a compact race-track microtron (RTM) which is under construction at the Universitat Politècnica de Catalunya (UPC). The RTM end magnets are four-pole systems with the magnetic field created by a rare-earth permanent magnet material. As a source of electrons a 3D off-axis electron gun is used. These elements together with a C-band accelerating structure, extraction dipole magnets and a focusing quadrupole are placed inside a vacuum chamber.

INTRODUCTION

A compact race-track microtron (RTM) with the maximal output energy 12 MeV is under construction at the UPC in collaboration with the Skobeltsyn Institute of Nuclear Physics (SINP) of the Moscow State University, CIEMAT and a few Spanish industrial companies and medical centers [1] (see Table 1).

The accelerator head consists of electron gun (1), linac (2), end magnets (3, 4) and quadrupole (4) (see Fig 1). Beam (7) can be extracted from any of the four orbits with extraction magnets (6). These RTM elements are precisely fixed on a common platform (Fig. 2), placed in a box (not shown) playing the role of the vacuum chamber.

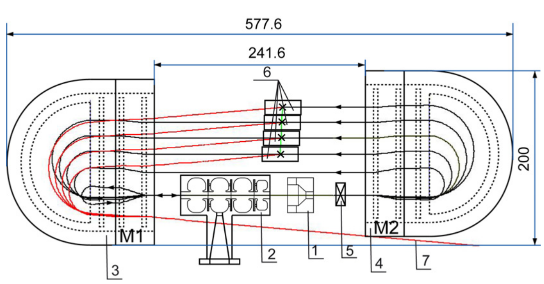

Figure 1: RTM schematic.

C-BAND LINAC

An on-axis coupled standing wave C-band linac, whose 3D model is shown in Fig. 3(a), provides a 2 MeV synchronous energy gain per turn. It consists of one short accelerating cell, optimized for efficient capture of 25 keV injected beam, three $\beta = 1$ accelerating cells and three coupling cells [2].

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Table 1: RTM parameters

Parameter	Value
Beam energies	6, 8, 10, 12 MeV
Operating wavelength	5.24 cm
Synchronous energy gain	2 MeV
End magnets field	0.8 T
Injection energy	25 keV
Pulsed RF power	<750 kW
RTM dimensions	578×200×123 mm
RTM head weight	< 80 kg

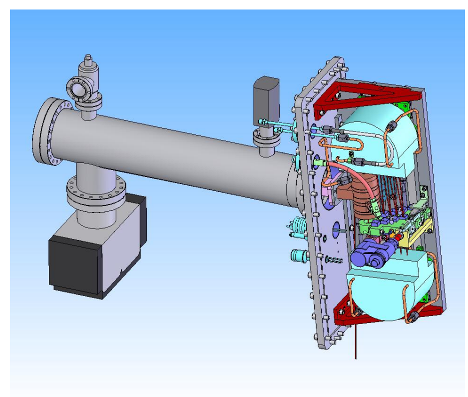
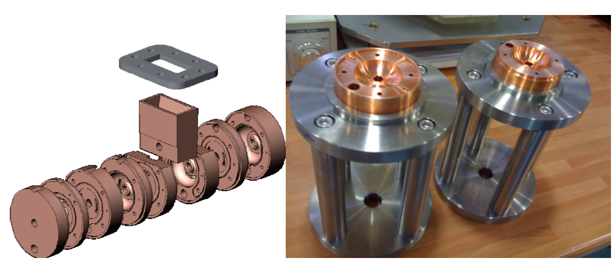


Figure 2: 3D view of the RTM head with open vacuum chamber.



(a) (b)

Figure 3: (a) 3D linac model, (b) Segments of the test cell prepared for measurements.

As a first step, a test cavity has been designed and machined with the aim to validate the design and to make sure that the tolerances (±20 μm) and roughness (<0.4 μm), required for the final machining of the cells, can be achieved. This $\beta = 1$ cavity is formed by two OFHC copper segments without coupling slots. In Fig. 3(b) the segments, prepared for low power RF measurements, are given. The measurements have shown that the resonance frequency differs in 0.1 % from HFSS simulations [3] and that Q factor is more than 90% of the calculated one. This allows to conclude that the chosen company can provide a sufficiently good machining of accelerating structure.

The ongoing task includes brazing of the test cavity, RF measurements and comparison of the RF characteristics before and after the brazing. A leakage test of cooling channels will also be performed. After these validation tests the whole accelerating structure will be machined and brazed.

END MAGNETS

Two four-pole end magnets, described in [4], provide beam recirculation through the linac. End magnet cross section is shown in Fig. 4. The main poles (1) and reverse poles (2), surrounded by properly magnetized Ni-plated Nd-Fe-B blocks (shown by filled areas) are fixed together by Al frame (3) and inserted in yoke (5). A precise distance between the poles is kept by means of insertion (4). Two additional pole assemblies (6) are installed at the magnet entrance. Cooling tube (7), placed in the median plane, provides end magnet temperature stabilization. Currently the end magnet task is at the stage of finishing the engineering design.

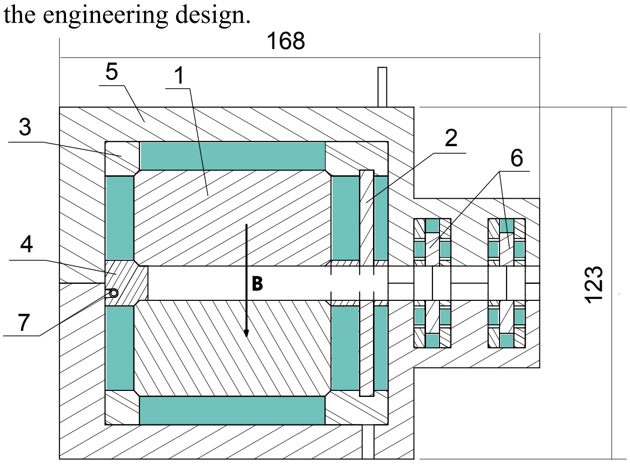
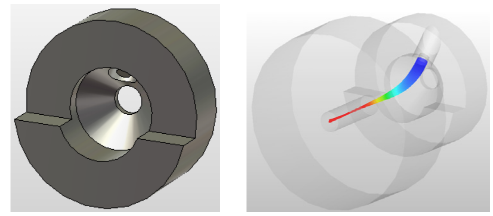


Figure 4: End magnet cross section.

ELECTRON GUN

The function of the electron gun is to supply 25-30 mA pulse current at 25 keV with a pulse duration 3 µs. The beam radius at the position of the entrance of the first linac cell must be below 1 mm.

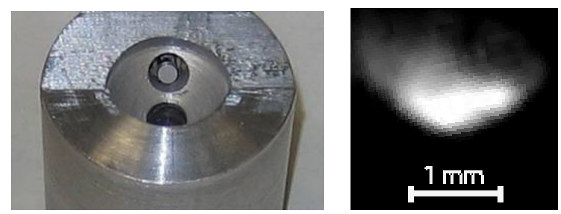
To provide beam recirculation through the linac we designed, constructed and tested an electron gun with off-axis beam injection. A focusing electrode, shown in Fig. 5(a), directs the beam towards the linac axis with the crossover at the first cell entrance. The calculated beam trajectory is shown in Fig. 5(b). The 4 MeV beam passing through the gun region gets angular deviation less than 1 mrad.



(a) (b)

Figure 5: Focusing electrode (a) and beam trajectory (b).

We use a tungsten impregnated cathode with the active area diameter of 3.5 mm capable to operate in a poor vacuum (10^{-3} Pa). The cathode filament power is ~5 W, estimated lifetime is ~10^4 hours.



(a) (b)

Figure 6: (a) Focusing electrode with the cathode installed, (b) Beam image obtained in prototype tests.

To validate the design and verify results of previous simulations an electron gun prototype was constructed and tested in a special test vacuum chamber at the SINP. For this a focusing electrode (Fig. 6 (a)) and an anode with 8 mm beam hole diameter were machined from an Al alloy. Inside the anode hole, at a distance corresponding to the position of the first linac cell entrance, a 20 µm thick isolated Ti foil, orthogonal to the beam direction, was placed. The foil surface, opposite to the beam incidence, was covered by a thin layer of phosphor so that it could be viewed with a CCD camera via a glass window. The foil current was measured with an oscilloscope at 50 Ohm input. The gun was fed by a modulator with regulated high voltage pulse amplitude.

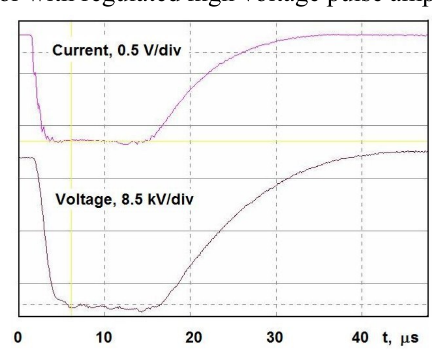


Figure 7: High voltage and current pulses.

The prototype tests have shown that the simulated and registered (Fig. 6(b)) beams are in a good agreement both in beam shape and dimensions. As it can be seen in Fig. 7, where a pulse of the foil current and that of the modulator high voltage are presented, the pulsed current at 25 kV high voltage amplitude is about 28 mA that is in a good agreement with calculations. The vacuum in the chamber during the tests was deliberately kept at level 10^{-3} - 10^{-4} Pa, this guarantees the gun operation in the RTM with all its elements placed inside the vacuum box.

RF SYSTEM

The RTM RF system architecture is shown in Fig. 8. Pulses of the power up to 1 MW are generated by SFD-313 [5] magnetron (1) at 5712 MHz and are supplied to the linac via the following series of elements: flexible waveguide (2), pressure unit (3), four-port circulator with terminations (4), H-bend with arc detector (5), dual loop coupler (6), rotary joint (7), vacuum window (8), and rigid (9) and flexible (10) waveguides. The magnetron is fed by a solid state ScandiNova [6] modulator (0).

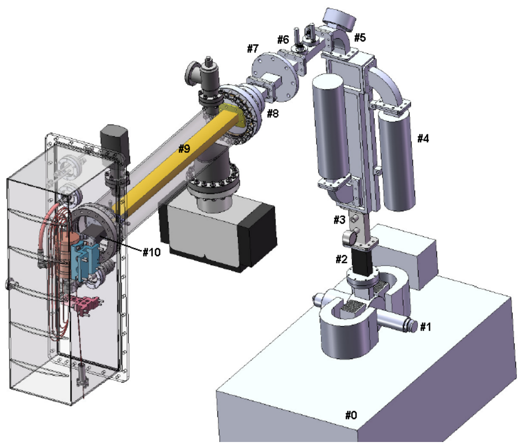


Figure 8: RTM RF system elements.

The waveguides are filled with SF_6 gas with 2 bars of excessive pressure. The function of the arc detector is to protect the circulator and vacuum windows from a damage by RF discharges. Waveguide (9), placed in vacuum, has slots in the narrow walls near the linac to improve its pumping out. The manufacturing of the magnetron and modulator have been already ordered. Currently the measurements of RF characteristics of the delivered elements are carried out.

Incident and reflected RF signals from the dual loop coupler are used by automatic frequency control (AFC) system whose function is to tune the magnetron frequency to the linac resonant frequency. It is envisaged that a fast frequency stabilization will be provided by an injection locking system using a signal from a linac coupling loop.

VACUUM CHAMBER

The elements of the RTM head are placed on a platform, bolted to a panel (see Fig. 2) and covered by a housing to form the vacuum chamber where a vacuum level of ~10^{-5} Pa is maintained during the RTM operation. The chamber is pumped out through a pumping tube shown in Fig. 2. The panel, housing and tube are made of non-magnetic stainless steel. The design has been optimized with a finite element analysis to minimize the weight and assure a safe level of stresses (< 130 MPa) and small displacements (< 0.5 mm). The housing is made out of 3 mm thick plates, with several 3 mm reinforcement ribs, whereas the panel is a 19 mm thick plate, with holes for feedthroughs of various systems (RF signal, high voltage, cooling water tubes, control signals). The engineering design of the vacuum box is finished and its manufacturing will be ordered soon.

The correct beam dynamics and quality of the extracted beam require very precise alignment of the magnets, linac and other elements in all working positions of the RTM head. This is guaranteed by a sufficient stiffness of the platform. All the structural components inside the vacuum chamber are made out of aluminum alloy to reduce the weight. The end magnets are mounted on sliding guides so that their position can be adjusted. The extraction magnets are moved by an electric motor placed outside the box, and their position is controlled by a displacement transducer.

To provide the vacuum level ~10^{-5} Pa at the position of the flange of the vacuum chamber it is permanently pumped out by a 75 l/s ion pump. At the initial stage of operation, after closing the vacuum chamber, the pre-vacuum is created by a ~ 60 l/s turbomolecular pump system which is temporary attached via a valve and a flexible hose.

CONTROL SYSTEM

The control system controls the operation of all systems, provides an operator interface and assures the safety of the RTM operation via interlocks. All RTM systems, except the modulator, are supervised at low level by TI TMS320F28335 100MHz microcontrollers communicating with a console PC via RS-485 to Ethernet-fiber media converter. LabView [7] is used at the console to supervise the RTM operation. The modulator Ethernet-copper interface is also transformed to fiber attached to the main PC. The hard wired interlocks provide safe RTM operation, their state is monitored by a separate microcontroller connected to the console PC.

CONCLUSIONS

The engineering design of the compact UPC RTM and its subsystems has been finished, manufacturing of elements and equipment acquisition are in progress.

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