

OPERATIONAL EXPERIENCE WITH 55 MEV PULSED RTM

A.N.Ermakov, V.V.Khankin, N.I.Pakhomov, V.I.Shvedunov, SINP MSU, 119992 Moscow, Russia
A.I.Karev, V.G.Raevsky, P.N.Lebedev Physical Institute, RAS, 119991 Moscow, Russia

Abstract

Operational experience with 55 MeV pulsed race-track microtron (RTM) is reported. The upgrade of the accelerator after the commissioning and some results of the physical experiments with a beam of the RTM are presented.

INTRODUCTION

The 55 MeV RTM [1] was designed and manufactured in framework of the contract between Lebedev Physical Institute (Russia) and Lawrence Livermore National Laboratory (USA). The purpose of the work consists in development of an effective photonuclear detector of hidden explosives [2].

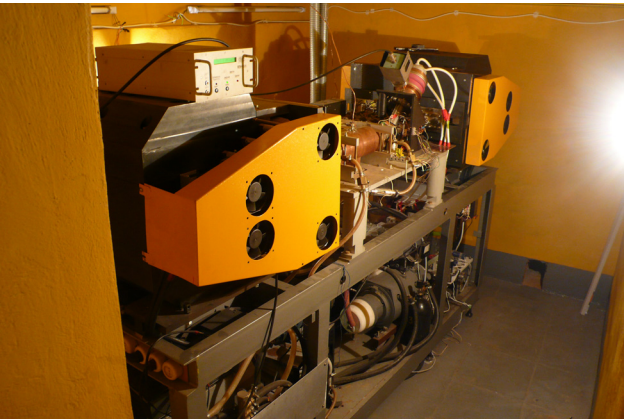


Figure 1: RTM photo.

Table 1: RTM parameters

Output energy	55 MeV
Output pulse current	Up to 10 mA
Repetition rate	6.25 – 50 Hz
Number of linac passages	11
Energy gain / turn	5 MeV
Current pulse length	6 μ s
Operating frequency	2856 MHz
End magnet field	1.0 T
Maximum RF power	6 MW
Orbit circumference increase / turn	1 λ

RTM has been built following a classical scheme with two 1 T end magnets and a standing wave linac between them providing 5 MeV energy gain per pass. A 50 keV beam from an electron gun is injected into linac through a 45° magnet and a solenoidal lens. The 5 MeV electron beam after the first acceleration is reflected by the end magnet field back to the linac axis and is accelerated up to 10 MeV - the energy sufficient to bypass the linac at the next turn. The beam is extracted from the last orbit with a

dipole of 17.5° deflecting angle. The RF system is based on a 6 MW multibeam klystron KIU-168 [3]. A pumping port, a vacuum window, and a circulator are installed between the linac and the klystron. Parameters of the vacuum window and the circulator during commissioning restricted the maximum RF power transported to the linac by 2.5 MW and thus restricted a maximum exit pulsed beam current. To simplify the RF system we use a auto-oscillation mode of klystron operation with accelerating structure in a feed-back loop [4]. More details about the RTM systems can be found in [1].

RTM commissioning had been conducted at temporary place at SINP MSU accelerator hall and temporary solutions had been used for some RTM systems. During commissioning the first physical experiment also had been conducted with RTM beam after which the work to install RTM at designated area with final solutions for its systems has been done. The main RTM parameters are listed in Table 1.

UPGRADE OF THE RTM SYSTEMS

Since the last report [1] part of the RTM systems have been upgraded, specifically: RF system, gas system, system of high voltage power supply, control system and beam diagnostics. The accelerator has been moved to specially built bunker in order to reduce background radiation in experimental hall. Photo of RTM in bunker is shown at Fig. 1.

RF System

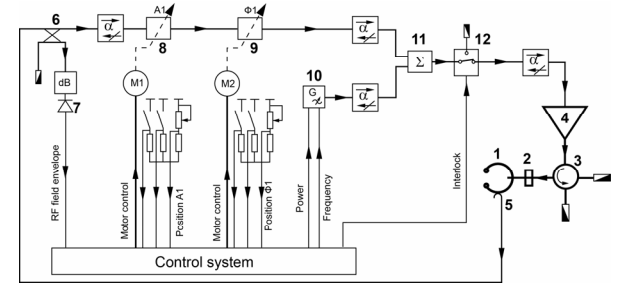


Figure 2: RTM RF system. 1 - accelerating structure, 2 - vacuum window, 3 - circulator, 4 - klystron, 5 - RF antenna, 6 - directional coupler, 7 - RF diode, 8 - attenuator, 9 - phase shifter, 10 - RF generator, 11 - RF power combiner, 12 - RF switch.

Upgraded RTM RF system is shown in Fig. 2. Klystron operation in auto-oscillation mode has several advantages as compared with traditional scheme with excitation from external generator, the most important is automatic following of the oscillations frequency to frequency of accelerating structure. However in pulsed mode the RF

field building up from the klystron noise is accompanied by essential jitter of leading edge of a RF pulse. In upgraded version of RF system we modified feedback circuit by admixing low power, ~ 10 mW, “ignition” RF signal from external generator and thus decreased the RF pulse front jitter to less than $0.1 \mu\text{s}$. There is no need to adjust generator frequency to oscillation frequency with accuracy better than ± 1 MHz.

To remove limitation in RF power which can be supplied to linac new 6 MW vacuum window and circulator were installed between linac and klystron instead of 2.5 MW units used during commissioning.

Gas System

The gas system shown in Fig. 3, provides automatic support of isolating SF_6 gas pressure at 2 bars and automatic procedure for waveguide system filling by gas and for gas replacement. Gas system consists of a gas cylinder with reducer, two solenoidal valves, pressure gauge, safety valve and diaphragm pump. Operation of system is controlled by dedicated microcontroller, integrated into RTM control system.

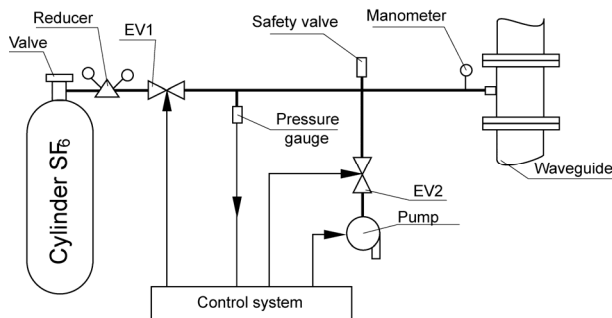


Figure 3: Gas system.

High Voltage Modulator



Figure 4: High voltage modulator.

A new high voltage modulator shown in Fig. 5 have been built by “Protom Ltd” [5] to feed RTM klystron and electron gun. Modulator principle of operation is based on

a PFN charged to 20 kV by high voltage power supply and discharged by TGI1-3K/30 thyatron to 1:6 pulse transformer connected with klystron. Additional thyatron of the same type is used to cut of the trailing edge of a high voltage pulse. The modulator provides 10 μs pulses with maximal amplitude 60 kV, current 280 A at repetition rates from 6.25 Hz to 50 Hz synchronized with the mains. Pulse top flatness is within $\pm 0.3\%$. High voltage pulse form is shown in Fig. 5.

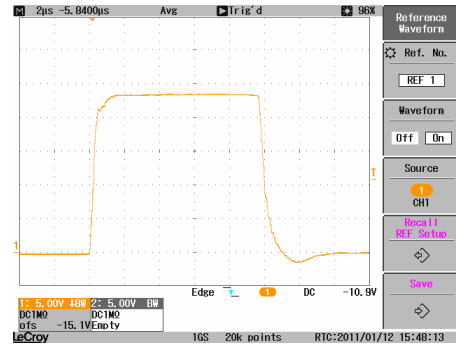


Figure 5: High voltage pulse.

Control System and Beam Diagnostic

Control system of upgraded RTM was built using standard National Instruments modules for signals control and LabView software [6]. Operator interface, providing access to control of current sources feeding steering coils and end magnets, to control of RF system, modulator and gas system is show in Fig. 6. By clicking an appropriate element at diagram the window with element parameters is opened providing possibility for their adjustment.

Beam diagnostic was improved by using multiplexer at oscilloscope input which allows to view beam current signals simultaneously from all beam current monitors, installed at RTM orbits.

To get better beam transmission through RTM orbits additional steering coils were installed at 3, 5, 7 and 9 orbits.

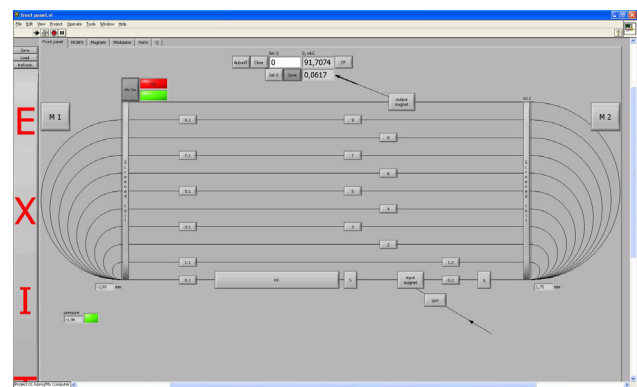


Figure 6: Screenshot of operator interface.

PHISICAL EXPERIMENTS WITH RTM BEAM

Production of the F18-Isotope With Electron Accelerator

The positron activity radionuclide F^{18} is perspective isotope for Positron Emission Tomography (PET). Now this isotope is produced by means of proton or deuteron beams from cyclotrons. But F^{18} may be obtained from $^{23}Na(\gamma, \alpha n)^{18}F$ reaction with bremsstrahlung radiation. To study the possibility F^{18} production for nuclear medicine the metal Na sample was irradiated by bremsstrahlung from 55-MeV RTM electron beam [7]. In Fig. 8. it is shown a typical spectrum of secondary γ -quanta from irradiated target, measured by high purity Ge spectrometer.

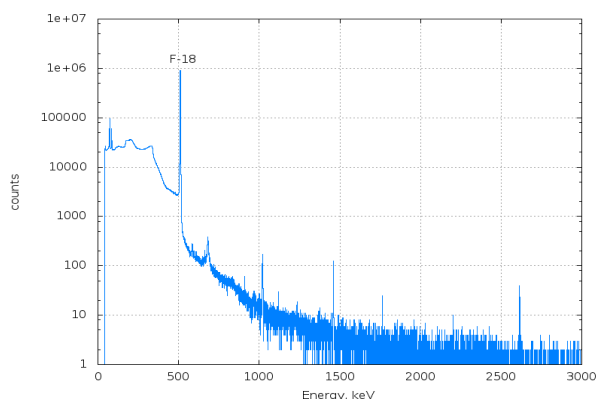


Figure 5: The γ -spectrum from the irradiated ^{23}Na sample.

This experiment shows that at the average beam current $\approx 40 \mu A$, the Na target thickness $\approx 5 \text{ g cm}^{-2}$, and the irradiation time $\approx 5.5 \text{ h}$, the produced activity can be as high as $\sim 0.1 \text{ Cu}$, what is about necessary level.

Besides there was studied production of ^{18}F in reaction $^{19}F(\gamma, n)$ using $(C_2F_4)_k$ – targets [8]. Results of this work for total produced activity of ^{18}F and, respectively, value of moment of cross section σ_{-1} are in reasonable agreement with known data for maximum energies of γ -quanta up to $\sim 28 \text{ MeV}$.

Radiation Safety of the Photonuclear Method for Detection Explosives

The photonuclear method for detection of hidden explosives is based on registration of short-lived ^{12}N and ^{12}B radioisotopes, which are produced when a sample with carbon and nitrogen is irradiated by high-energy photons. The carbon and nitrogen are base of the modern explosives and by means of the analysis of the time-spectrum of the secondary radiation from sample the explosive may be identified. However, the irradiation of a sample with arbitrary chemical composition is able to create many different radionuclides which may be dangerous [9].

To assess the level of the radiation safety (or danger) for case when photonuclear detector will be used for inspection of airline passengers' luggage the experiments with RTM beam were done. The samples imitated the contents of the luggage were irradiated by bremsstrahlung photons as they will be irradiated in the real inspection procedure. The list of the samples included the different kinds of natural and synthetic textiles, shoes, metals (steel, copper, aluminium, gold and silver in jewelry), and gadgets (camera, radio, watch, etc). After the irradiation the dose and dose rate from the samples was measured. Besides the radioisotopes in the samples was analyzed by means of high purity Ge spectrometer. As a result of the experiments it was shown that dose from 20 kg bags is very low and the irradiated luggage is not dangerous for passengers and airport staff.

CONCLUSION

As a result of RTM upgrade higher beam stability and higher beam current are obtained with more simple tuning procedure. Radiation shielding bunker strongly reduced background radiation thus permitting to conduct more accurate experiments.

The authors would like to thank prof. B.S. Ishkhanov and Dr. L.Z. Dzhilavjan for providing by results of physical experiments.

REFERENCES

- [1] A.I.Karev, A.N.Lebedev, V.G.Raevsky, et al, RuPAC-2010, p. 316-318
- [2] A.I.Karev, V.G.Raevsky, J.A.Konyaev et al, Patent RF #2226686. Filed Dates: August 14, 2002, RF.
- [3] I.A. Frejdovich, P.V. Nevsky, V.P. Sakharov et al, Proceedings of IVEC-IVESC 2006, Report N13.5
- [4] A.N. Ermakov, D.I. Ermakov, B.S. Ishkhanov et al, Instruments and Experimental Techniques, Vol. 45, No. 4 (2002) 482–489
- [5] www.protom.ru
- [6] www.ni.com/labview/
- [7] S.S.Belyshev, L.Z.Dzhilavyan, A.N.Ermakov, et al, Moscow University Physics Bulletin, 2012, Vol. 67, No. 3, pp. 246–250.
- [8] S.S.Belyshev, L.Z.Dzhilavyan, A.N.Ermakov, et al. LXII International Conference NUCLEUS 2012, Saint-Petersburg, p. 246.
- [9] L.Z.Dzhilavayan, A.I.Karev, Bulletin of the Russian Academy of Sciences. Physics, 2011, Vol.75, No.11, pp.1557-1561.