55 MEV SPECIAL PURPOSE RACE-TRACK MICROTRON COMMISSIONING*

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Abstract

Results of Lebedev Physical Institute RAS 55 MeV special-purpose race-track microtron (RTM) commissioning are presented. RTM is intended for photonuclear detection of hidden explosives based on initiation of photonuclear activation and consequent registration of secondary gamma-rays penetrating possible screening substances.

INTRODUCTION

The purpose of the work consists in development of an effective photonuclear detector of hidden explosives to be used under stationary conditions and in mobile systems for searches of field mines. The detector consists of a source of high energy gamma - radiation and counters fixing the secondary radiation from decay of short-living isotopes formed in explosives due to reactions with nitrogen and carbon nuclei [1]. The gamma source is based on a specialized microtron (RTM) for energy of 55 MeV. A RTM photo is presented in Fig. 1, main RTM A RTM photo is presented in Fig. 1, main RTM parameters reached by commissioning are listed in Table 1.

Figure 1: RTM photo.

Table 1: RTM parameters

Output energy	55 MeV
Output pulse current	10 mA
Repetition rate	5 – 50 Hz
Number of linac passages	11
Energy gain / turn	5 MeV
Current pulse length	5 μs
Operating frequency	2856 MHz
End magnet field	1.0 T
Maximum RF power	2.5 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 45^0 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 17.5^0 deflecting angle. More details about the RTM scheme can be found in [2].

RTM SYSTEMS

RF system

The RF system is based on a multibeam klystron KIU-168 [3] with a rare earth permanent magnet focusing system providing 6 MW/6 kW pulsed/average power at 2856 MHz. The klystron is compact, its high voltage pulse amplitude is only 54 kV, so it does not need oil insulation and can be installed under the RTM table. A pumping port, a vacuum window, and a circulator are installed between the linac and the klystron.

The non-vacuum part of the waveguide tract is filled with SF_6 at 2 bars. Parameters of the vacuum window and the circulator by commissioning restricted the maximum RF power transported to the linac by 2.5 MW and thus restricted a maximum exit pulsed beam current by 10 mA. The klystron is fed by a "hard" modulator [4] with pulse duration up to 15 μs. To simplify the RF system we use a self-oscillation mode of operation with linac structure included in a feed-back loop [5]. Optimal conditions for self-oscillations and for RF power level regulation are controlled with a phase shifter and an attenuator installed in the feed-back loop. In Fig. 2 the klystron current, the high voltage and RF field pulses are shown. The 8 μs high voltage pulse duration is set externally. The delay of about 3 μs between the high voltage front and RF pulses is the time required for building-up self-oscillations from the noise. This time can be decreased by adding a low power "igniting" RF signal to the feed-back loop.

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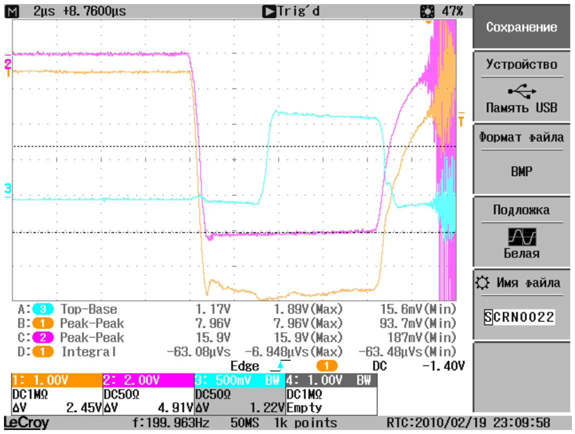

Figure 2: Klystron current (1), high voltage (2), and RF field (3) pulses.

Electron gun

A three electrodes electron gun with a 8.6 mm diameter tungsten impregnated cathode for nominal current of 400 mA and beam energy of 50 keV is used in RTM (Fig. 3(a)). By varying intermediate anode voltage the

(a) (b)

Figure 3: (a) Electron gun, (b) magnets power supply.

gun current can be controlled within ±100 mA. The electron gun is fed with the same modulator as the klystron is. A voltage at the intermediate anode regulated in discrete steps is provided from the high voltage divider installed inside the RTM table. The electron gun is pumped with 5 l/s ion pump, vacuum in the gun being better than 10^{-5} Pa.

Magnets power supply system

To feed the coils of the end magnets current sources Genesys™ type form TDK-LAMBDA [6] are used. Two GEN 12.5-60 current sources feed reverse pole coils while two GEN 60-55 sources are used for the coils of the main poles. The rest magnetic elements are fed with a multichannel current source of 42 channels designed by Protom company [7]. Magnets power supply system is shown in Fig. 3(b).

Control system and beam diagnostics

RTM control system has been built using standard National Instruments modules for signals control and LabView software [8] for user interface.

Beam diagnostic is provided by beam current monitors (BCM) of 5 mV/mA sensitivity installed at each orbit and at the linac axis, by synchrotron radiation, and by transition radiation. To observe synchrotron radiation from RTM orbits with CCD camera a glass window in the vacuum chamber was installed at the end magnets. Accelerated beam was extracted to atmosphere through 20 µm thick Ti foil. Transition radiation generated by the beam crossing the foil was registered by a CCD camera. Extracted beam absorbed in a Faraday cup provides a beam current signal.

RTM TUNING

Before RTM tuning the distance between the edges of the end magnet main poles was set according to calculated value with accuracy ±0.1 mm. The level of the main and reverse field was adjusted to calculated values using a calibrated Hall probe with accuracy 0.1% and 1%, respectively. Care was taken to decrease hysteresis phenomena influence on the field level when switching on/off current sources.

The main factors influencing on the beam propagation in the transverse plane of RTM are end magnets field errors, parasitic and strayed magnetic fields, an inaccuracy in magnets and linac positioning, an inaccuracy in longitudinal beam dynamics tuning. In longitudinal plane the main factor is uncertainty of the accelerating field level which absolute value can not be well determined by RF diode calibration or by measuring of linac dissipated RF power via cooling water temperature and flow.

To decouple longitudinal and transverse plane tuning we calibrated the RF diode signal against beam energy using end magnets combined with BCMs placed at 1st and 2d orbits. To accomplish this we calculated electron trajectories in the end magnet for various currents in the coils keeping constant a ratio of the main and reverse fields. Then we found a correspondence between the electron energy and the coils current when the beam passed through the centre of the first and the second orbit tubes.

At the second step we measured the beam energy spectrum after the first acceleration using 1st orbit BCM for various settings of the accelerating field. After the first acceleration the beam is reflected back to the linac by the end magnet (M1) moving counter clockwise. In order to enter 1st orbit tube at lower magnetic field the beam must move clockwise, so to measure spectrum we reversed the polarity of the M1 coils. In Fig. 4 at the left beam spectra measured after the first acceleration at various field levels are compared with a spectrum found in RTM beam dynamics simulation (black dots). The energy resolution of spectrometer is defined by the inner diameter of the tube and is rather poor. We fixed the RF diode voltage for pink curve as one corresponding to nominal accelerating field.

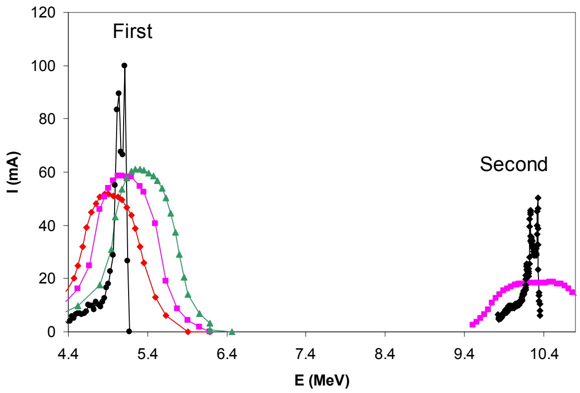

Figure 4: Measured beam spectra after first and second acceleration compared with calculated.

At the next step we set the proper polarity and level of the M1 field, so the beam was reflected back to the linac and accelerated in opposite direction. Than with second magnet (M2) and 2^d BCM we controlled beam energy (right pink points curve at Fig. 4). One can see that the measured beam spectrum maximum (~ 10 MeV) well coincides with maximum of spectrum found in beam dynamics simulation (black points). From these results it follows that the beam enters the linac after reflection by M1 in a proper phase.

Note that after the first acceleration the beam current is about 50-60 mA (this value is defined by the gun current and injection system tuning), while after the second one it falls down to about 16 mA, an essential part of the low energy tail of the beam being stopped by the linac wall. Current losses are somewhat higher than following from calculations – compare amplitudes of calculated spectra (which are in arbitrary units).

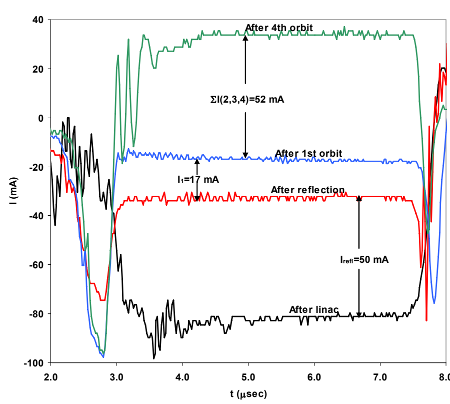

Figure 5: Signals from BCM installed at linac axis.

Additional valuable information about beam reflection by M1 and following acceleration can be obtained from BCM installed at the linac axis between the linac and M1 magnet. In Fig. 5 signals from BCM obtained under different conditions are shown. Black curve was obtained with M1 magnet off. Beam current coming out of the linac in this case is about 80 mA. After M1 switching on a current registered by BCM decreased for about 50 mA – this was the beam current reflected from M1 and passing BCM in opposite direction. After 1^st orbit the BCM signal dropped to 17 mA and after the forth additionally to 52 mA (meaning a sum of the 2,3 and 4^th orbits current) changing signal polarity. From these data it follows that RTM can be tuned with minimal beam losses after 1^st orbit.

In order to get beam transmission shown in Fig. 6 currents of the steering coils installed at the injection path and at RTM orbits were adjusted using information from BCM. We should note that the RF power necessary to accelerate 16 mA beam up to the last orbit exceeds the damage limit of the vacuum window and circulator. So for further RTM tuning the beam current was decreased by decreasing the gun current and by deliberate current losses in the injection path.

In succeeding RTM tuning by steering coils additional information from CCD camera viewing synchrotron radiation (Fig. 6) and from a Faraday cup was used.

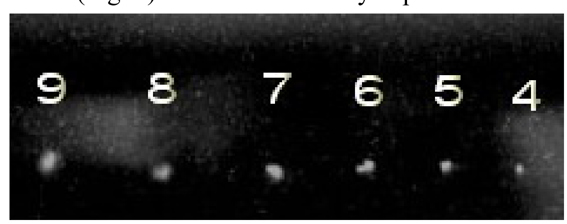

Figure 6: Synchrotron radiation beam image for 4-9 orbits.

CONCLUSION

As a result of RTM tuning the pulsed beam current of 10 mA was obtained at RTM output. This value was limited by parameters of available RF elements. A new 6 MW window, and circulator have been purchased. After their installation a higher beam current is expected.

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