VARIANTS OF OPTICS SCHEMES AND ACCELERATOR CONFIGURATIONS FOR THE ATHENS MICROTRON: PRELIMINARY CONSIDERATIONS.

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I. INTRODUCTION.

The IASA **C**ontinuous **W**ave **R**ace **T**rack **M**icrotron will be built from the components of 185 MeV/550 μA NIST/LANL research RTM project. The original NIST CW RTM was designed as 15 linac passages accelerator with increase in orbit circumference per turn $\nu = 2$, 12 MeV synchronous energy gain per turn and quadrupole doublets on each return path. Being outstanding in a number of projected parameters this well-developed design differs by complexity of accelerator tuning connected with chose injection scheme and beam optics. Nuclear physics experiments planned for IASA RTM requires an increase of output beam energy to about 250 MeV, which cannot be achieved with the original design. By this report, we present the results of comparative study of the original design with other possible variants that can be realized with NIST RTM equipment and which differ in accelerator configuration and beam optics. We compared different variants from the point of view of longitudinal and transverse acceptances' values, sensitivity to misalignments, output energy attainable, RF power consumption. From different variants considered we present here original scheme (Variant 1); scheme with $\nu = 1$ and high injection energy (Variant 2); and cascade scheme (Variant 3) in which available second end magnets pair can be used. Schematic views of these variants are shown in figure 1, and their parameters are given in Table I.

Table I. RTM parameters for different configurations.

RTM variants	1	2	3 - I	3 - II
Injection energy (MeV)	5	17	5	42.5
Energy gain per turn (MeV)	12	6	1.6	8
Incremental number, ν	2	1	1	1
Number of linac passages	15	28	25	25
Output energy (MeV)	185	185	42.5	245
Maxim current (μA)	550	100	100	100
End magnets field (Tesla)	1	1	0.266	1.33
Linac length (m)	8	4	1.6	8
Linacs RF losses (kW)	305	305	24	106
A_{tr} (π mm x mrad)	36	105	30	90
A_{lon} (π MeV x deg)	0.6	3.6	1	10

II. RTMS VARIANTS

A. NIST RTM (variant 1).

The original goal of the NIST RTM project (figure 1a) was to investigate the feasibility of building a 1-2 GeV high current CW accelerator using beam recirculation with normal conducting accelerating cavities [1]. Tightly interconnected choice of $\nu = 2$, high energy gain per turn and focusing elements on the return paths determine the features of longitudinal and transverse beam dynamics for NIST RTM. For $\nu = 2$ region of longitudinal phase stability is about two times smaller than for $\nu = 1$; and quadrupole doublets on the return paths produce unavoidable longitudinal and horizontal motion coupling. To decrease this coupling period of betatron oscillations in the original design is chosen to be close to 8, and longitudinal - 4. First orbit problem is solved by complicated “hairpin” injection scheme - after first linac passage beam is reflected by the end magnet fringe field and accelerated in opposite direction, thus increasing effective injection energy to 21 MeV.

We have calculated RTM beam dynamics with RTMTRACE code [2] to estimate longitudinal (A_{lon}) and normalized transverse (A_{tr}) acceptances and sensitivity of longitudinal motion to elements misalignments and errors in fields settings. We present in the Table I values of the acceptances and in Table II sensitivity factors, which are values of change in distance between end magnets Δd, change of accelerating field phase with respect to injected beam $\Delta\phi$, relative change in accelerating field amplitude $\Delta E/E$, and relative change in end magnets field $\Delta B/B$ which lead to amplitude of synchronous particle longitudinal oscillations ~ 2^{o}

Table II. Sensitivity factors.

Variant	Δd (mm)	$\Delta\phi$ (degr.)	$\Delta E/E$ (%)	$\Delta B/B$(%)
1	0.15	0.9	0.1	0.06%
2	0.37	2.4	0.5	0.14
3	0.41	2.2	0.65	0.14

B. Reconfigured NIST RTM (variant 2).

Figure 1b shows RTM schemes that can be realized with minimal rework using NIST RTM equipment. In this variant one from two linacs sections is transferred from the

RTM axis to injector. Increasing the injection energy to 17 MeV with the magnetic mirror installed at the injector output and having 6 MeV synchronous energy gain per turn we get injected beam orbit diameter 7.4 cm - too small to bypass linac. The problem of linac bypass can be solved with the injection scheme originally used at MAMI RTM I [3] and schematically shown at fig. 1a. Thus, $\nu = 1$, 28 orbit RTM can be realized with the beam focusing by quadrupole doublets installed at both linacs sides on the common axis. This simple optics similar to that used in MAMI RTMs [3] posses enough strength to ensure stable transverse oscillations for our choice of injection to output energies ratio 17: 185 despite to the quadratic focusing strength decrease with the energy growth.

Our computer simulation showed that due to $\nu = 1$, high injection energy and short distance between end magnets this variant has ~ 3 times larger longitudinal acceptance, than variant 1, ~ 6 times larger normalized transverse acceptance, and is about 2 -3 times less sensitive to elements misalignments and fields errors

RTM tuning and operation is significantly simplified in considered scheme, but part of the problems connected with accelerator tuning and operation is transferred from the RTM to injector. On the other hand, high current, small longitudinal and transverse emittances beam with energy varying between 6 and 17 MeV can be obtained at the injector output in relatively short time and used in applied researches. Magnetic mirror can be realized according to one of the known schemes - it can be isochronous achromatic four magnets system, similar to that of ref. 4, or has more simple construction being one dipole magnet with special field configuration as described in [5]. To output beam from the injector three magnet chicane must be installed between the existing 5 MeV line and added accelerator section. New line to transport and inject beam to RTM must be designed and manufactured.

Linacs RF power losses in variant 2 is nearly the same as in the original scheme so output energy cannot be essentially increased

C. Cascade scheme (Variant 3).

Cascade scheme was originally suggested in [3] and successfully realized in three steps MAMI accelerator with 850 MeV output energy [6]. Accelerator tuning and operation is greatly simplified in this case as compared with the original NIST/LANL design. RF power consumption is essentially decreased thus giving possibility to increase output energy. Two pairs of end magnets available at IASA make this solution quite realistic.

View of the cascade scheme is given in figure 1c. Both RTMs are $\nu = 1$, 25 orbit machines. Original linac with it's 8 m length is installed in RTM II, operating at low energy gradient ~ 1 MeV/m, thus consuming only ~ 106 kW RF power without beam load. RTM I 1.6 m linac with the same energy gradient consumes ~ 24 kW RF power, and matching section placed between two steps has much less power consumption.

Choice of the RTM I output energy for a given end magnet dimensions is dictated by the necessity of linac bypass for injection energy 5 MeV. In this case simplest injection scheme shown in figure 1c can be used for both RTMs.

Similar to variant 2, simple optics with beam focusing by quadrupole doublets installed at the both linacs sides on the common axis for RTM II and singlets for RTM I are used, having higher strength , than in variant 2 as the ratios of input to output energies are smaller for both cascades.

Calculated values of the longitudinal and normalized transverse acceptances and sensitivity factors are given in Tables I and II, respectively. RTM II acceptances are rather large being close to that of variant 2. For RTM I owing to large phase slip on the few first orbits and low injection energy acceptances are more close to the original design. Sensitivity factors for both steps are close to variant 2, thus cascade scheme is less sensitive to elements misalignments and field errors, than the original design.

The crucial point of cascade scheme for the present 245 MeV design is possibility to achieve high field uniformity at the field level ~ 1.3 - 1.4 T with the available end magnets, which were designed for 0.8 -1.2 T gap field. We have made POISSON [7] calculations which showed, that to get field homogeneity $2\ 10^{-4}$ at the gap field level 1.33 T it is necessary slightly increase shim thickness as compared with the original design. For higher field levels owing to steel saturation field inhomogenety become too high to be compensated by shim thickness. Method of current shims used for MAMI RTMs [6] can be used in this case

Comparing with previous variants cascade scheme requires much more labor for its realization. New linacs must be designed and manufactured for RTM I and matching system, though this problem can be solved by one of two 4 m main linac sections reassembling [8]. In this case ~ 6 m linac will be used for RTM II and two ~ 1 m linacs for RTM I and matching system. With the decreasing linacs length RF power consumption will proportionally grow, being within available 500 kW klystron capabilities.

III. CONCLUSION.

Possibility to get 245 MeV output energy, RTM I beam with the energy ~ 40 - 45 MeV, which can be used in applied researches, inherent simplicity in tuning and operation make the cascade scheme to be favorable choice. Additional calculations to get matching conditions for different variants and more extensive misalignment effects estimations will be made. The final choice of IASA RTM scheme depends both on the relative technical merits and amount of labor needed to build and operate accelerator.

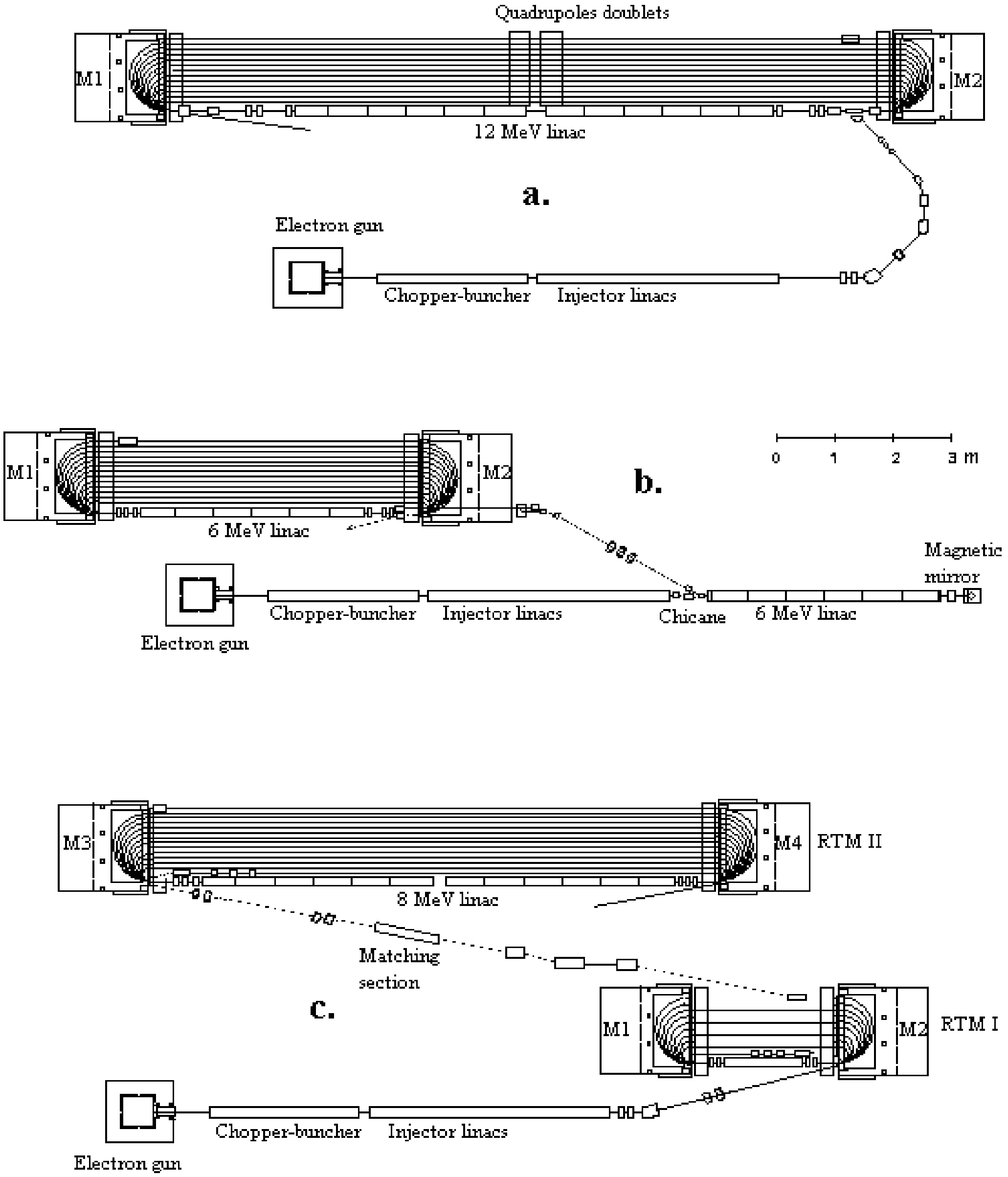

Figure 1. Variants for IASA CW RTM.

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