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# New possibilities for nuclear physics experiments with Novosibirsk Race-Track Microtron-Recuperator.

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The race-track microtron-recuperator (RTMR) with a high power free electron laser in the last straight section is under construction for the Siberian Center of Photochemical Researches in Novosibirsk [1]. This machine can be used also for nuclear physics experiments with broad possibilities.

In many applications, a beam of charged particles is not significantly changed after passing through a "user device". Thus, electrons lose only a small part of their energy in a magnetic wiggler; in a collider the particle loss per one pass through the collision point is also small. Storage rings are successfully used in such cases with the most important applications being colliding beams, X-ray sources, free electron lasers and internal target experiments. The beam power (the product of current and particle energy divided by the particle charge) here is very high but it is reactive as the beam circulates in the storage ring for a long time being repeatedly used. Due to the multiple use and quantum fluctuations of the synchrotron radiation, the energy spread and/or emittance grows lowering the performance level. Therefore the use of the "fresh" beam is sometimes preferable. The specific feature of accelerator-recuperators is that charged particles are accelerated and then decelerated. This offers an opportunity to have the "fresh" beam with high reactive power. The energy recovery of the used beam saves the consumed power and dramatically decreases the radiation hazard compared to the case when the high energy beam is absorbed in a beam dump.

The attractive possibility is to decelerate particles in the same RF cavities where they were accelerated. In this approach the decelerated beam returns energy directly to electromagnetic field in cavities, so (i) there is no problem of high power transfer between the accelerator and the decelerator, and (ii) the number of RF cavities and, therefore, the RF power consumption, is two times less. The price for these advantages is the necessity of a complex magnetic system which must provide a stable recirculating beam. The most complicated and expensive part of such a set-up is the RF system but its cost can be reduced with the use of multiturn acceleration and deceleration. The only existing machine

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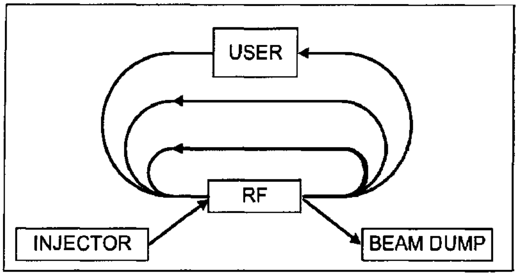


| | |
|---|---|
| Electron energy | 98 MeV |
| Beam current | 50 mA |
| Energy dispersion | 0.2% |
| Repetition frequency | 2-22.5 MHz |

Figure 1. The general scheme of a multiturn RF accelerator-recuperator (left panel) and the main beam parameters of Novosibirsk RTMR (right panel).

of this type is used for an infrared free electron laser (IFEL) at TJNAF (USA). Another one under construction in Novosibirsk [1] is also dedicated for IFEL. But, as discussed below, the Novosibirsk race-track microtron-recuperator (RTMR) may be used for a broad range of nuclear physics experiments. At present, an electron injector of RTMR is put into operation with beam energy 2 MeV and current 50 mA, all resonators are assembled, and magnetic elements are in production.

A special by-pass for nuclear experiments may be introduced in the RTMR where a target with a thickness up to $10^{-3}$ of the radiation length can be placed without a sizable influence upon beam dynamics. It gives a possibility to reach very high luminosity

$$L \approx 10^{40}/Z(Z+1) \quad \mathrm{cm}^{-2}\mathrm{s}^{-1}.$$

Being intermediate between internal and external target methods, this approach can combine the advantages of both. Thus, for electron scattering experiments with registration of slow secondary particles, one can choose a suitable thickness of the target retaining at the same time high luminosity.

As an example, the foil targets with thickness equal to the range of $\alpha$-particles with energy 1 MeV provide, at various conditions, the following luminosities:

| Element | U | Fe | Al |
|---|---|---|---|
| Target thickness, mg/cm$^2$ | 3.4 | 1.6 | 1.0 |
| Deposited power, W | 340 | 160 | 100 |
| Target temperature, $^\circ$ C | 530 | 400 | 330 |
| Luminosity, cm$^{-2}$s$^{-1}$ | $2.6 \cdot 10^{36}$ | $5.3 \cdot 10^{36}$ | $6.8 \cdot 10^{36}$ |

Here we show also the power lost by the electron beam passing through the targets, and the temperature of target manufactured as a rotating ring with radius $R = 10$ cm and $\delta R = 1$ cm. This temperature corresponds to the equilibrium of beam loss power and heat radiation from the target. The serious problem of high power loss, $P \approx L \cdot Z \cdot 10^{-36}$ W, should be taken into account at the target design. Along with the foils, dust [2] or liquid jet targets look promising. In both cases the required target thickness can be obtained, and the problem of jet heating can be solved. With a jet target, the temperature increase and the velocity of the jet are related as $v \approx 1000/\Delta T^\circ$ m/s, assuming that the heat capacity of the jet material is 1 J g$^{-1}$ K$^{-1}$.

A problem of random coincidence can restrict the use of high luminosity. The cross section for a process with a scattered electron and emitted proton detected in coincidence may be expressed as $d^2\sigma_{\rm eff}/d\Omega_e dE_e \approx (d^2\sigma_e/d\Omega_e dE_e) C L k_\gamma \sigma_\gamma \tau$ where $C$ is the ratio of the effect/random coincidence counting rates, $d^2\sigma_e/d\Omega_e dE_e$ is the cross section that determines the electron detector counting rate, and we assume that for the proton detector counting rate the photonuclear cross section $\sigma_\gamma$ dominates; $k_\gamma$ is a number of equivalent photons. If the protons from the process under study and from photonuclear processes have a uniform angular distribution, the target is the $^{16}$O , $C \geq 10$, the initial and final electron energy is 100 MeV and 50 Mev, respectively, and the resolution time is $\tau = 10^{-9}$ s, we obtain $d^2\sigma_{\rm eff}/d\Omega_e dE_e \geq L \cdot 10^{-68}$. For this case and at luminosity $L \approx 10^{37}$ cm$^{-2}$s$^{-1}$, the cross section of the studied process should not be smaller than $\approx 10^{-31}$ cm$^2$.

Very high luminosity allows one to turn the physical program in the direction of the experiments which would be hardly possible for conventional electron scattering facilites. The processes with well pronounced specific features but with relatively low cross sections are of particular interest. Below we briefly discuss a few examples.

Recently a remarkable phenomenon of "pionic fusion" of two $^{12}$C nuclei into $^{24}$Mg and $^{24}$Na was observed [3] at very low energy above kinematical threshold (the cross section is of the order of 200 pb). This is an example of extreme collectivity when nearly entire energy of global motion is radiated as a single pion. The critical role of nuclear structure, conservation laws and Pauli principle in such processes was stressed in [4]. The inverse process would be the pionic fission of $^{24}$Mg. Its electromagnetic analog, electrofission, can be theoretically considered in the same approach. The known electrofission experiment $^{24}$Mg $\rightarrow ^{12}$C+$^{12}$C [5] gave $d^2\sigma/d\Omega_{\rm c.m.} dE \approx 1$ nb sr$^{-1}$MeV$^{-1}$ in the maximum around excitation energy 21 MeV in $^{24}$Mg. For the fission channel $^{16}$O+$^{8}$Be with the subsequent decay of $^8$Be into two $\alpha$-particles, the cross section is greater by an order of magnitude. There are no data available for the electrofission of the $^{32}$S nucleus which would be a suitable candidate.

The interest to such processes as pionic fusion and electrofission is related to new avenues of nuclear collectivity which become accessible with the experimental progress. The study of such phenomena can shed light on a poorly understood composite structure of nuclei. The description of clusterization phenomena up to now did not reach the stage of the development compared to that in the shell model. Meanwhile the cluster components of nuclear wave functions are extremely important not only in typical alpha-nuclei as $^{12}$C or $^{16}$O but in heavier nuclei as well, as seen from exotic radioactivity and other experimental data, see for example [6]. From this point of view, even the study of khockout $(e, e'\alpha)$ on a new level of statistics and accuracy, started in the first experiments with the internal superthin target [7], would be of great interest. The process of alpha-preformation inside a complex nucleus is not understood, and there are theoretical predictions of experimental signatures of virtually excited states of the originally formed cluster [8]. The observation of the nuclear restructuring in knockout reactions becomes possible with high statistics. The knockout of slow $\alpha$ from $^{16}$O can also give information on the inverse process of radiative $\alpha$-capture by $^{12}$C which is important for astrophysical applications.

Another possible direction of using the new facility would be for inelastic scattering with excitation of specific nuclear states. Only recently the first relatively successful separation of multipole form-factors (Coulomb C0 and transverse E2 and M1) was performed [9] at

Mainz with the aid of the $(e, e'\gamma)$ reaction with an unpolarized target for the $1/2^- \rightarrow 3/2^-$ transition in $^{15}$N. In fact, the statistical uncertainties at low momentum transfer $q = 0.63$ fm$^{-1}$ are too large to make the conclusions reliable. This region of momentum transfer is the most appropriate for the project under discussion. High statistics will allow one to not only separate multipoles but also determine single-particle occupancies which would provide a very sensitive test of the shell model for the excitation which is usually considered as a pure single-particle one. The proton hole transition $3/2^+ \rightarrow 1/2^+$ in $^{39}$K is of similar nature and can be studied analogously.

Collective shape degrees of freedom also can be probed with this set-up. One can even discuss a new possibility of exciting double phonon states because the smallness of the cross sections related to the second order of electromagnetic interaction is compensated by high luminosity (in Coulomb excitation one uses high-$Z$ targets [10]). Such an experiment is very clean compared to heavy ion reactions. In particular, the double giant dipole resonance states and low-lying two-phonon collective states are to be considered as candidates. Although, because of small $q$, it is hardly possible to determine the transition formfactors with the same precision as for the octupole vibration in $^{208}$Pb [11], the determination of transition charge radii for the double phonon states would be a serious check of nuclear models.

Although Compton scattering was widely explored for study of nucleon and nuclear polarizability, its precise measurement in a set up close to that suggested for the NEP storage ring [12] but with much higher luminosity of the RTMR is very attractive.

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