DUBNA PROJECT OF THE HEAVY ION STORAGE RING COMPLEX K4-K10

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ABSTRACT

The project consists of two cooler rings (4 and 10 $T \times m$) connected by the fragment separator.[1)] The JINR U400M cyclotron will be the injector for the K4 ring.The cooled primary beams obtained as short (20ns) bunches after the fast extraction from the K4 are focused onto a small target.This reduces considerably the transverse and longitudinal emittances of the produced secondary exotic beams,thus facilitating their cooling after injection into the K10 ring.The K4 - K10 complex will provide the luminosity values on internal targets of 10^{24} - $10^{28} cm^{-2}s^{-1}$ with beams of such ions as ^6He,^8He,^{11}Be,^{16}C,^{38}Ar etc. having lifetimes $> 0.1s$.

We specify the main purpose of the project by dedicating it to the producing of high precision Exotic Ion Beams (EIB's) with $A < 100$. Production of EIB's imposes specific requirements on such a heavy ion complex.

The layout of the storage ring complex K4-K10 is shown in Fig 1 together with the one of the heavy ion cyclotrons of the JINR (Dubna). The project includes two rings, K4 and K10. The beam channels related to this project are also shown in Fig. 1. These are the channel guiding from the U400M[2)] cyclotron to the injection section of the ring K4 and the fast beam extraction line of the K4 ring followed by a fragment separation channel allowing the injection of EIB's into the K10 ring. The fast and slow extraction beam lines from the K10 ring are envisaged as well.

Two long straight sections of the K4 ring and one long straight section of the K10 ring are reserved for experiments employing internal targets.

Basic parameters of the rings are listed in Table 1.

We are intended to provide the highest possible electron beam density in the coolers of both the rings in order to reduce the cooling time. For the same reason, we optimized the ring structures in a way allowing relatively high values of amplitude functions at the cooler section straights. The reduction of the cooling time in both rings is essential for the production rates of beams of short lived exotic nuclei.

Rather powerful RF-systems are planned for the rings especially for the ring K10. This provides necessary conditions for generating short bunches before beam extraction from the K4 ring. In the case of the K10 ring we need a high RF amplitude to manipulate the large momentum spread EIB's injected on the ring orbit.

Fragmentation reactions of medium energy heavy ions with mass numbers $A < 100$ will be used for producing the EIB's. Primary heavy ion beams ($\epsilon_\perp = 15\pi mm \times mrad$, $\Delta p/p = 0.15\%$) will first be accelerated by the U400M cyclotron and then injected into the ring K4. Cooled and additionally accelerated in this ring the ion beam, after the fast extraction in the form of a short, about 20 ns bunch, will be focused on the production target of less than 1 mm in its diameter. This causes the reduction of both the transverse and longitudinal emittances of secondary EIB's produced on this target and greatly facilitates the reduction of the EIB cooling time on the orbit of the ring K10.

The primary ion accumulation time in the K4 ring will be rather short ($= 60ms$) in the case of the stripping injection of light ions ($A < 20$). For heavier ions the multiple single turn injection is proposed. This method of accumulation employs the beam emittance contraction due to electron cooling to open the space for successive events. Single-turn injection is prefered due to the capability to retain the quality of the injected beam. In addition, by keeping the cooling electron velocity equal to the mean velocity of the injected ions one minimizes the beam cooling time. For the case of the single turn injection of the $^{48}Ca^{10+}$ beam extracted from the U400M

Ring		K4	K10
$B\rho_{max}/B\rho_{min}$	(T·m)	4.0/0.7	10.0/0.7
Circumference	(m)	83.12	146.24
Acceptance			
$\varepsilon_{\perp}$	(π mm*mrad)	50	25
$\Delta p/p$	(%)	1.0	2.0
Electron cooling section			
$E_{e\ max}$	(keV)	100	250
Length	(m)	3	3
$I_{e\ max}$	(A)	1.0	3.0
Cathode diameter	(cm)	3	3
β_h/β_v	(m)	10.9/6.3	5.6/5.8
RF-system			
f_{max}/f_{min}	(MHz)	3.6/0.4	2.09/0.25
harmonic number		1	1
number of stations and RF amplitude	(n·kV)	1·14	4·14

TABLE 1 Basic parameters of the rings K4 and K10.

cyclotron and stripped before the injection into the K4 ring to the charge state 20+ the value of the injection and cooling time of about 200 ms is evaluated for 10^9 ions stored on the ring orbit.

Fast extraction from the K4 ring should routinely provide beams with momentum spread and bunch length of about ±0.2% and 20 ns correspondingly. The beam momentum spread of ±0.2% is still tolerable from point of view of focussing onto a small target.

The momentum loss achromat technique is utilized in the design of this separator channel.[3] It is designed to transmit EIB's with the value of emittance $\epsilon_{\perp} = 25\pi mm \times mrad$ and momentum spread of ±0.5%.

The design of the K10 ring provides the possibility to keep simultaneously two beams on the orbit, i.e. the newly injected beam with mean momentum p_{inj} and another one corresponding to the momentum shifted by about 1.5% from p_{inj}. We suppose that the newly injected EIB beam bunch is immediately captured within a stationary RF bucket in such a way that this bunch occupies a phase interval of about 7^o being ±0.5% in its value of momentum spread. We take the height of the separatrix two times larger than the minimum value U_{RFmin} needed for the capture of the full size injected bunch. Such a value of U_{RF} prevents the injected beam bunch from serious filamentation during the quarter period of the synchrotron oscillation. After completion of the quarter period of synchrotron oscillation, two ways of the ring operation are possible.

For those short-lived ($T_{1/2} < 1s$) EIB's for which the accumulation on the ring orbit has no sense a specific ring operation mode is of interest. In this case, the RF is switched off just after completion of the quarter period of synchrotron oscillation. The electron cooling system matched to p_{inj} cools the beam both longitudinally and transversely within a time interval of $< 100ms$. This cooled beam is used immediately for experiments on an internal target.

For long-lived EIB's ($T_{1/2} > 1s$) for which accumulation is reasonable the RF stacking procedure[4] should be applied. The RF matching of the EIB bunch should be performed just after injection. As the first stage, the RF matching implies a quarter period synchrotron oscillation. After the RF matching the beam acceleration towards the working orbit takes place. We assume

Primary beam	EIB	$T_{1/2}$, s	N	L, $cm^{-2}s^{-1}$ (injection energy)	E_{max} (MeV/nucl.)	L, $cm^{-2}s^{-1}$ (maximum energy)
^{7}Li	^{6}He	0.8	$3\ 10^{7}$	$2\ 10^{27}$	430	$1\ 10^{27}$
^{18}O	^{8}He	0.122	20	$2\ 10^{21}$	260	$1\ 10^{20}$
	^{11}Be	13.8	$4\ 10^{7}$	$4\ 10^{27}$	500	$2\ 10^{27}$
	^{15}C	2.45	$3\ 10^{7}$	$2\ 10^{27}$	580	$1\ 10^{27}$
	^{16}C	0.747	$2\ 10^{6}$	$2\ 10^{26}$	520	$1\ 10^{26}$
^{48}Ca	^{44}Ar	720	$3\ 10^{7}$	$2\ 10^{27}$	600	$1\ 10^{27}$
	^{46}Ar	7.8	$4\ 10^{4}$	$3\ 10^{24}$	560	$2\ 10^{24}$
	^{47}K	17.5	$5\ 10^{7}$	$6\ 10^{27}$	590	$3\ 10^{27}$
	^{38}S	$1\ 10^{4}$	$2\ 10^{8}$	$2\ 10^{28}$	630	$1\ 10^{28}$
^{18}O	^{8}He	0.122	$1\cdot 10^{4}$	10^{24}		
	^{11}Li	0.009	$1.2\cdot 10^{3}$	$1.2\cdot 10^{23}$		

TABLE 2 Estimations of numbers of some exotic ions and the relevant luminosities available on the orbit of the ring K10. The given values are calculated for the internal target of $10^{14} cm^{-2}$.

that the beam accumulated on the working orbit is used in experiments with an internal target. This beam is permanently cooled and new beam portions approaching, due to RF stacking, the working orbit are left free at some distance from it. We count on the electron cooler which will cool new beam portions thus equating their momentum with the beam momentum on the working orbit. Cooling time of about one second can be reached in this case. Some results of calculations for the luminosity values which can be achieved with different EIB's in experiments making use of internal targets in the K10 ring are presented in Table 2.

The K4-K10 project is the subject of considerations by the JINR scientific community as a major facility planned for construction within next five years. Proceeding from the general policy of the JINR, we want to make the new heavy ion complex open for research groups coming from the JINR member states as well as from any other research centers. This imposes on us the responsibility for providing the necessary performance features of the complex.

We used in this paper results of the Technical Proposal[5] prepared by the K4-K10 design group.

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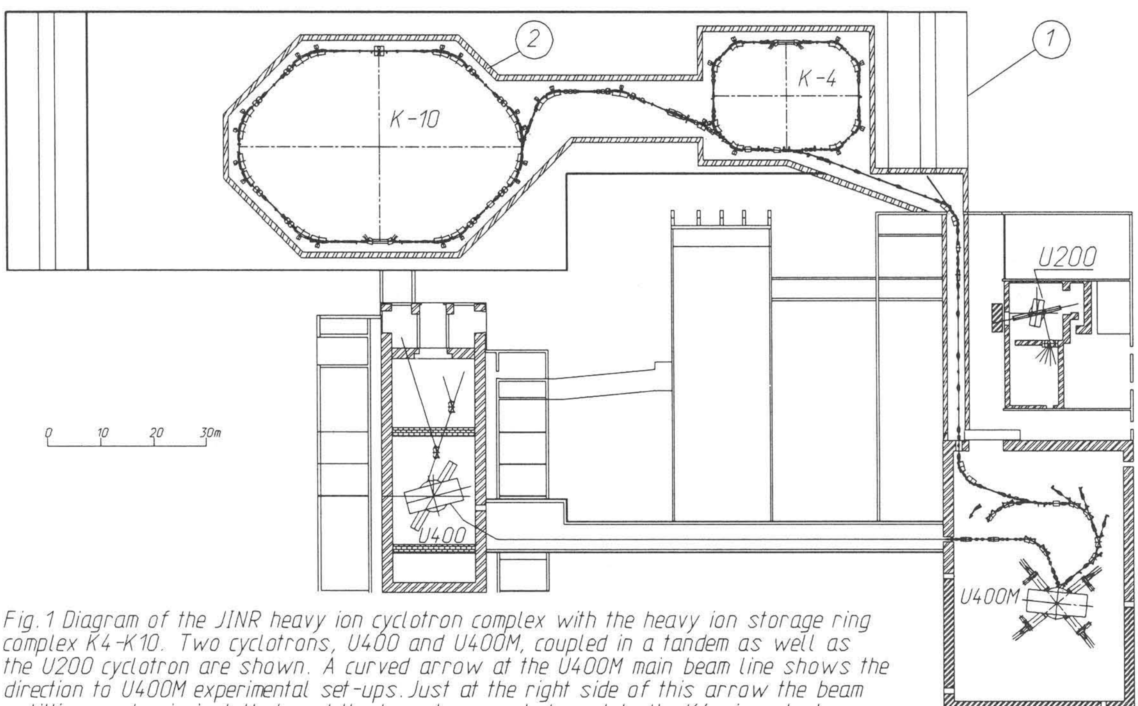

Fig. 1 Diagram of the JINR heavy ion cyclotron complex with the heavy ion storage ring complex K4-K10. Two cyclotrons, U400 and U400M, coupled in a tandem as well as the U200 cyclotron are shown. A curved arrow at the U400M main beam line shows the direction to U400M experimental set-ups. Just at the right side of this arrow the beam splitting system is installed ,and the beam transport channel to the K4-ring starts.
1-perimeter of a building projected for the K4-K10 complex, 2-concrete shielding of projected rings and beam lines.