INJECTION INTO A MULTIFUNCTIONAL ACCELERATOR COMPLEX

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By modeling the beam motion in the recirculator of the MAC multifunctional acceleration complex, the maximum value of the injection beam emittance was found, at which it is impossible to avoid the loss of beam intensity at the recirculator outlet.

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INTRODUCTION

The main goal of developing a conceptual design and, subsequently, constructing a multifunctional accelerator complex (MAC) at the NSC KIPT is to create a material and technical base for the revival of nuclear physics research and a foundation for training specialists in this field in Ukraine [1]. When selecting the main parameters of the complex, the following were taken into account as the basis of the concept set out in the work [2] for the development of the experimental base of the NSC KIPT for fundamental and applied research in the field of nuclear physics, high-energy physics, and radiation-matter interactions, as well as the main trends in the creation of such facilities in Europe and worldwide [1, 3, 4].

The desire to create conditions for conducting the widest possible range of research at a single complex creates additional difficulties in selecting an electron injection and acceleration system for such a facility. To obtain quasi-continuous electron beams that meet the modern requirements of research in high-energy physics, nuclear physics, neutron physics, free-electron laser physics, and their use for the implementation of radiation technologies in industry, energy, medicine, biology, and other fields of science and technology, MAC proposes the use of superconducting accelerating structures, as in the vast majority of facilities currently designed and built [5-19].

Let us consider the requirements that must be met for the correct selection of injector parameters to ensure the efficient operation of the acceleration complex.

1. REQUIREMENTS FOR THE RECIRCULATOR INJECTION CHANNEL

The main purpose of the injection channel is to transport the electron source beam to the entrance of the recirculator rings and to ensure the necessary phase volume matching. From the point of view of beam optics, it is necessary to match the Twyss parameters at the electron source output with the Twyss parameters at the beam injection point into the recirculator ring, the values of which are [1, 4]:

• amplitude functions in the horizontal and vertical plane $\beta_x = \beta_y =$ 29.337 m;

• slopes of phase ellipses – 0.683.

As follows from the available materials on electron injectors [5–19], their main parameters are within the following ranges:

• beam energy E_0 = 4…9 MeV;

• geometric emittance $\varepsilon_{x,y}$ = 1…15 mm·mrad;

• energy spread δ = 5…15 keV;

• injector outlet beam diameter d = 4…5 mm.

To simulate injection and evaluate the acceptance of the recirculator [1,4], a beam with the following parameters was selected:

• maximum beam dimensions $\sigma_{x,y}$ = 2.5 mm;

• the beam is a crossover and its maximum divergence is determined by the emittance and the above dimensions;

• the beam duration is ± 3 mm (20 ps);

• pulse spread $\Delta p/p_0$ = ± 0.5%;

• all 100% of particles are located within phase ellipses with the above dimensions.

An example of matching the parameters of the injector and recirculator is shown in Fig. 1. Matching is performed by two quadrupole doublets after the accelerating module with an energy set ΔE = 25 MeV and a five-lens parallel beam transfer. This structure allows the phase volumes to be matched in all ranges of injection beam parameter variation.

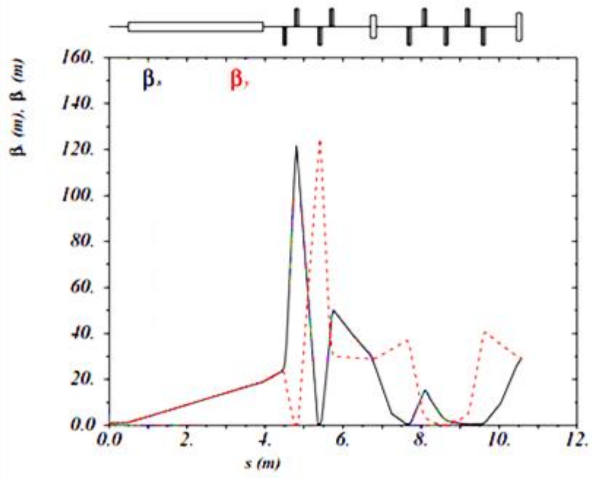

Fig. 1. Matching the injector and recirculator Twyss parameters

2. RECIRCULATOR ACCEPTANCE

The rotating magnets of the recirculator rings, which are intended for use [1, 4], have a fairly strong six-pole component of the magnetic field $K_2 = (1/B\rho)\partial^2 B/\partial x^2 =$ -15 T/m^2. As a result, the betatron oscillations of the beam are highly nonlinear, which is especially evident when injecting beams with large emittances, when the beam can be lost in the rings at the apertures of the equipment due to the degradation of phase volumes. In addition, a fairly significant spread of the beam in terms of energy leads to a significant impact on the dynamics of nonlinear momentum deviation effects. The limiting emittance of the beam, at which there are no losses, determines the acceptor of the installation.

To correct aberrations in the beam motion, sextupole lenses are provided, located in a specific manner on the recirculator rings [1, 4].

Figs. 2–5 show the phase portraits of the beams obtained in the simulation after the third pass of the main accelerator in both transverse planes without and with sextupole correction for the cases of beam injection with transverse emittances of 1 and 5 mm·mrad.

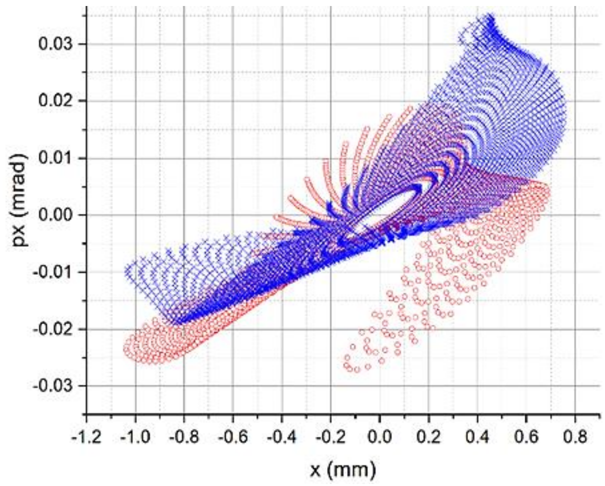

Fig. 2. Phase portraits of the beam in the radial plane at transverse beam emittance from the injector $\varepsilon_{x,y}$=1°mm·mrad. Red symbols – no correction, blue – corrected motion

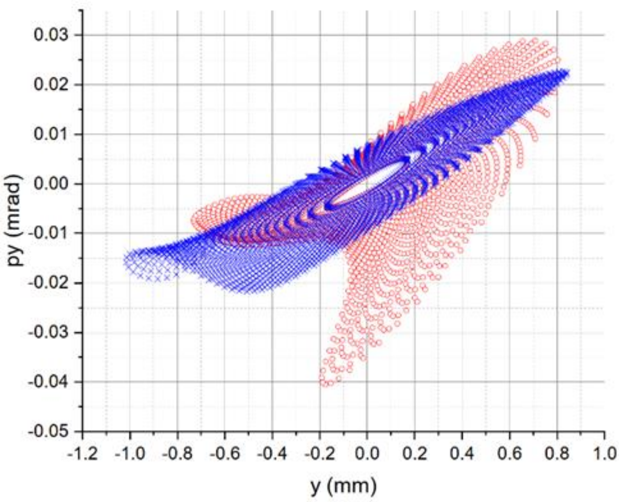

Fig. 3. Phase portraits of the beam in the vertical plane with transverse beam emittance from the injector, $\varepsilon_{x,y}$=1°mm·mrad. Red symbols – no correction, blue – corrected motion

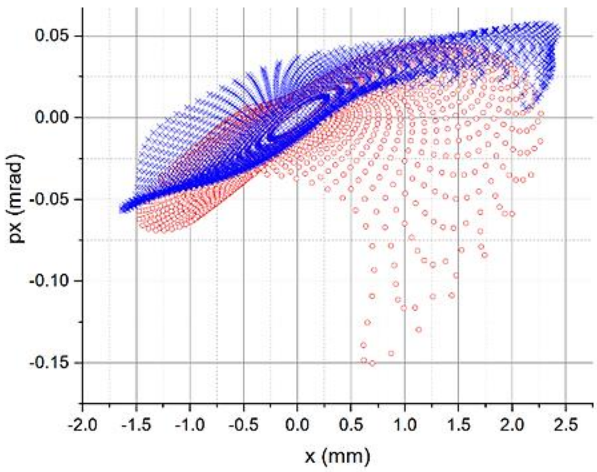

Fig. 4. Phase portraits of the beam in the radial plane at the transverse beam emittance from the injector $\varepsilon_{x,y}$=5 mm·mrad. Red symbols – no correction, blue – corrected motion

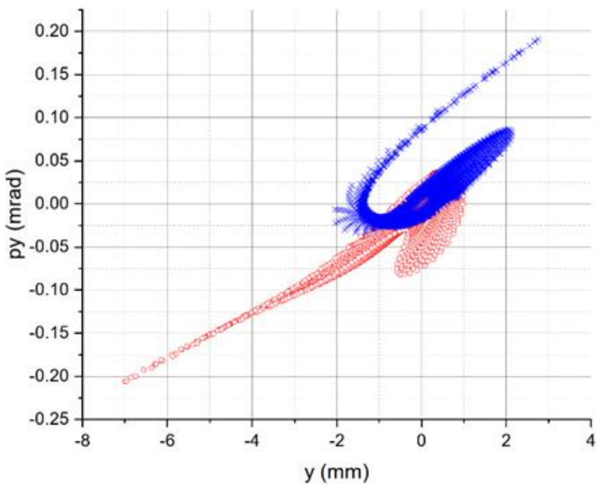

Fig. 5. Phase portraits of the beam in the vertical plane at the transverse beam emittance from the injector $\varepsilon_{x,y}$=5 mm·mrad. Red symbols – no correction, blue – corrected motion

When injecting a beam with an emittance of 6 mm·mrad, particles begin to be lost in the beam extraction channel with maximum energy; at an emittance of 7°mm·mrad, particles are already lost in the second ring of the recirculator. With some margin, the acceptor of the recirculator is determined by the transverse emittance $\varepsilon_{x,y}$= 5 mm·mrad at a longitudinal emittance ε_s=10·0.5 mm·%.

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ІНЖЕКЦІЯ ПУЧКА В БАГАТОФУНКЦІОНАЛЬНИЙ ПРИСКОРЮВАЛЬНИЙ КОМПЛЕКС

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За допомогою моделювання руху пучка в рециркуляторі багатофункціонального прискорювального комплексу МАС знайдено максимальну величину емітанса інжекційного пучка, при якій неможливо уникнути втрати інтенсивності пучка на виході рециркулятора.