DESIGN AND PERFORMANCE ANALYSIS OF THE UPGRADED TRANSFER LINE FOR TWO-PLANE INJECTION AT THE SIS18

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Abstract

Two-plane multiturn injection is planned for SIS18 to enable the delivery of high-intensity heavy-ion beams, which will subsequently be accelerated and extracted toward SIS100 at a repetition rate of 2.7 Hz. To accommodate this new injection scenario, the existing SIS18 injection line must be redesigned to allow simultaneous injection into both the horizontal and vertical planes of the synchrotron. Ion optic studies have been performed to evaluate the expected performance of the upgraded injection system, and the results are presented in this paper. The simulations demonstrate that the injection efficiency strongly depends on the emittance and transverse beam distribution of the beam delivered from UNILAC. Furthermore, unavoidable mismatches between the optical parameters of the injection transfer line and SIS18 can lead to a degradation of injection efficiency. To minimize the impact of such mismatches, beam collimation in the transfer line and its effect on beam characteristics are analysed.

INTRODUCTION

A part of TK injection transfer line is being redesigned to enable two-plane multi-turn injection into the SIS18 synchrotron, replacing the current single-plane (horizontal) scheme [1,2]. A key characteristic of two-plane injection is that the beam must arrive at the SIS18 injection point on a closed orbit displaced in both the horizontal and vertical planes, as illustrated in Fig. 1. To achieve this, the TK9 section of the TK line must be redesigned to facilitate simultaneous beam transport in the horizontal and vertical planes. Ion optic calculation and multiparticle tracking studies have been performed to analyze the beam parameters at the SIS18 injection point. Together with the upgraded UNILAC linear accelerator [3], the entire TK transport line - from UNILAC to SIS18 - must deliver a well-defined transverse beam profile characterized by low emittance and high intensity. The TK9 section, which currently comprises a magnetic septum and four quadrupole magnets, requires reconfiguration to support combined-plane beam transport while remaining fully compatible with the existing TK beamline extension from UNILAC as shown in Fig.2.

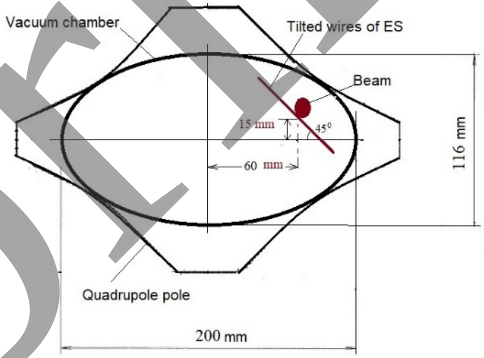

Figure 1: Injection point at SIS18, showing the vacuum chamber geometry and the pole shape of the quadrupole magnets located immediately downstream of the tilted electrostatic septum (ES). The closed-orbit displacement at the ES is x=60 mm, y=15 mm.

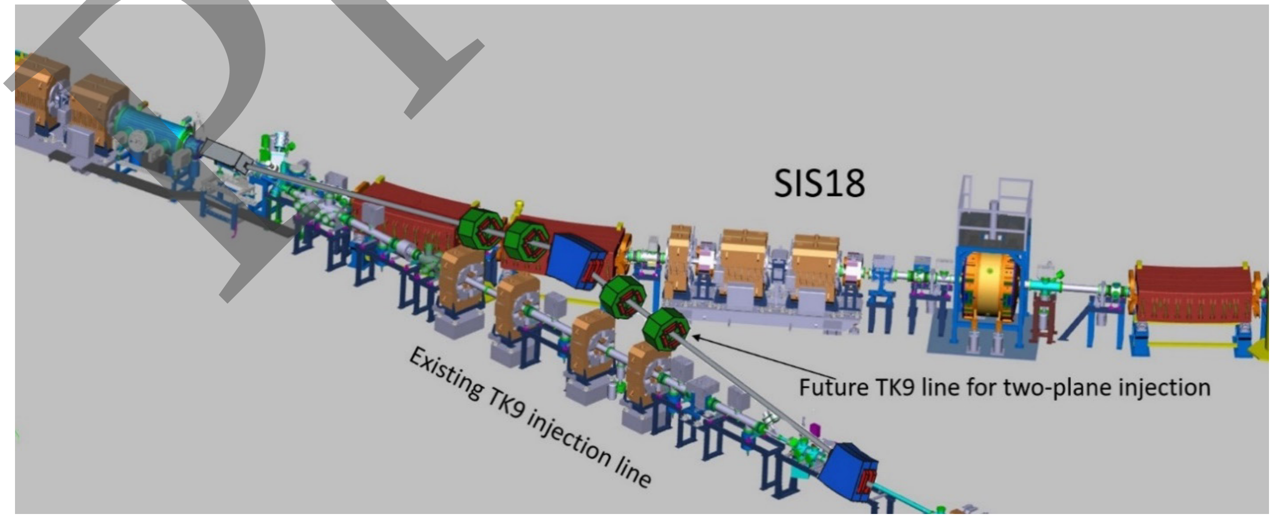

Figure 2: Layout of the Existing TK9 Injection Line and the Proposed New Configuration for Two-Plane Multi-Turn Injection Into SIS18

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OPTICS DESIGN OF THE TK9 LINE

To facilitate two-plane beam injection and transport, the existing TK9 beamline section will be replaced by a new dedicated TK9 injection line as show in Fig.2. This upgrade includes the installation of two dipole magnets providing deflection angles of +8° (GTK9MU11) and -16° (GTK9MU12). The dipoles and four quadrupoles should be arranged in a plane inclined at 70° with respect to the horizontal plane. A new electrostatic septum must be designed with the wires tilted at 45°. To ensure proper alignment, the existing magnetic septum GS12MU3I must also be tilted at 45° to match the inclination of the electrostatic septum (GS12ME1I) wires. Since the transport line introduces beam deflections in both the vertical and horizontal planes, horizontal and vertical dispersion functions are generated. Fig. 3 shows the coupled betatron and dispersion functions in the redesigned TK9 line, calculated using the Edwards-Teng parametrization.

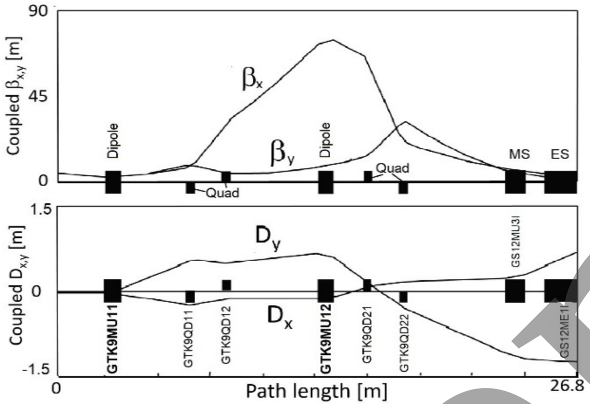

Figure 3: Coupled Betatron and Dispersion Functions in the Redesigned TK9 Transfer Line

Although the dispersion components at the end of line cannot be completely eliminated, their magnitude can be significantly reduced by applying a 30° roll angle to four quadrupoles of the TK9 line. By utilizing the full set of quadrupoles along the TK line, the desired beam sizes at the SIS18 injection point can be achieved. Figure 4 presents the calculated beam envelopes in the horizontal and vertical planes along the TK5–TK9 sections, assuming an emittance of 10 mm·mrad in both planes.

BEAM COLLIMATION IN TK LINE

As demonstrated in [2], achieving the required intensity of the U^{28+} beam with loss-free injection into SIS18 necessitates keeping the beam emittance (for 100% intensity) below 6 mm·mrad in both transverse planes. Numerous emittance measurements show that the beam emittance fluctuates significantly from pulse to pulse (typically by 30–50%). These fluctuations complicate the establishment of stable and reproducible injection conditions. To have a constant beam spot size at injection point the beam collimation in both transverse planes must be implemented along the TK line. Fig. 4 shows the set of combined horizontal and vertical collimators already installed in the TK line. The two existing horizontal collimators, GTK7DS1H and GTK7DS3H, form a 90° phase-advance pair, providing effective horizontal halo scraping. For efficient vertical beam collimation, an additional vertical collimator, GTK9DS1V, should be installed at a phase advance of 90° relative to the existing GTK7DS3V. This collimation strategy, combined with careful tuning of the TK line optics, provides a robust means to stabilize the injected beam parameters and achieve loss free injection into SIS18.

Effects of Coupling and Dispersion

Due to residual linear coupling in the TK9 section and the appearance of non-zero dispersion functions, the particle distribution at the SIS18 injection point becomes significantly inflated, with the extent of this blow-up depending strongly on the beam's momentum spread. For typical beam parameters, which are expected to be delivered from UNILAC (see Table 1), particle tracking was performed through the entire TK transfer line with and without beam collimation. Figure 5 illustrates the calculated beam intensity within a given beam emittance for both the non-collimated and collimated cases.

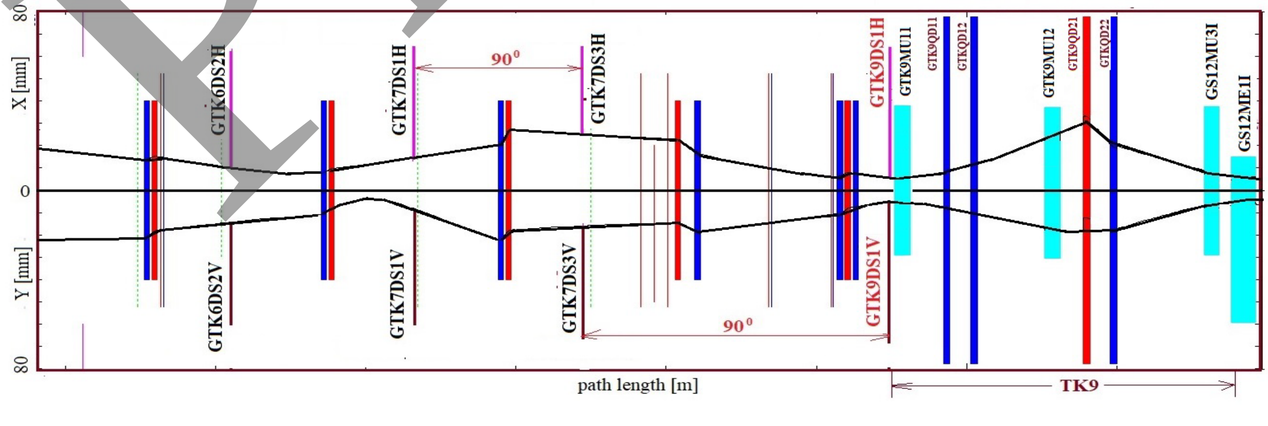

Figure 4: Beam envelopes in the horizontal and vertical planes along the TK5–TK9 sections for an emittance of 10 mm·mrad in both planes. Locations of the existing and proposed collimators (GTK6DS2H, GTK6DS2V, GTK7DS1H, GTK7DS1V, GTK7DS3H, GTK7DS3V) are indicated.

Table 1: Initial Beam Parameters at Beginning of TK Line

Parameters	**Value**
Ion species	p-U
Injection beam energy, MeV/u	11.4
Ion current (U^{28+}), mA	< 15
Momentum spread (1σ)	5 x 10^{-4}
Emittance hor/ver, mm·mrad (geom,100%)	< 15 / 15

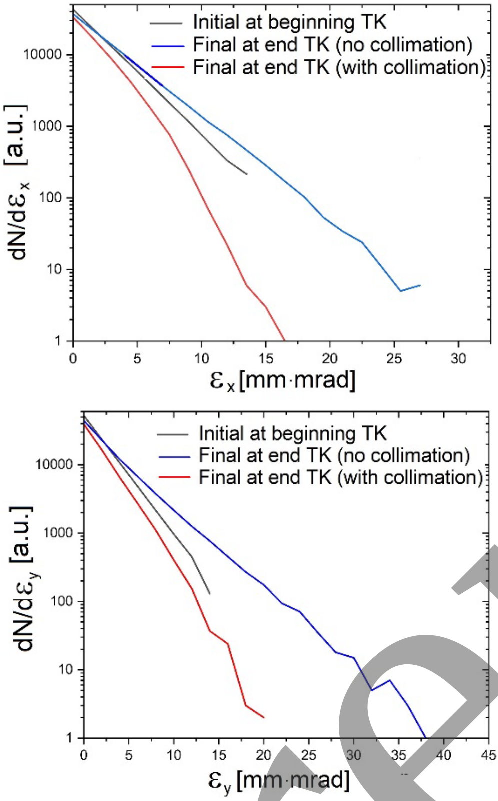

Figure 5: Intensity Distribution Within Horizontal (Top) and Vertical (Bottom) Emittance

For comparison, the initial intensity distribution at the beginning of the TK line is also shown in Fig.5, assuming a Gaussian particle distribution. Without collimation, the emittance for 100 % intensity increases from 15 mm·mrad to approximately 25 mm·mrad in the horizontal plane and to 37 mm·mrad in the vertical plane by the end of the TK line. With the application of collimation, the both effective eigenvalues of horizontal and vertical emittances can be reduced to 4 mm·mrad (4 rms), which represents an acceptable value for enabling efficient multi-turn injection into SIS18. Fig. 6 shows the particle distribution in the phase space of the SIS18 injection point. In comparison with the uncoupled reference case (emittance of 5 mm·mrad) the beam with the rms emittance of 4 mm·mrad exhibits significant smearing due to the coupled betatron and dispersion functions present in both horizontal and vertical planes. Applied collimation leads to an intensity loss of approximately 40 %.

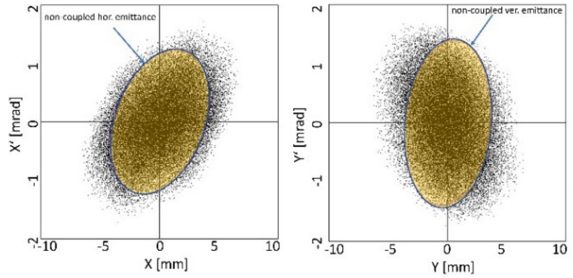

Figure 6: Particle distribution in the horizontal and vertical planes at the SIS18 injection point (end of TK line) after collimation.

CONCLUSION

The upgraded TK9 section of the SIS18 injection transfer line has been designed to enable efficient two-plane multi-turn injection of high-intensity heavy-ion beams. Ion-optical studies and multi-particle tracking simulations demonstrate that the proposed layout - incorporating new inclined dipole magnets, a tilted electrostatic septum, and an additional vertical collimator - provides the required beam parameters at the SIS18 injection point while remaining fully compatible with the existing UNILAC-to-TK beamline. Beam collimation in the TK line has been shown to reduce the transverse emittance to approximately 4 mm·mrad (4 rms) in both planes, which is essential for high-efficiency multi-turn injection. Although this comes at the cost of approximately 40 % intensity loss, the resulting beam quality satisfies the requirements for delivering the design U^{28+} intensity to SIS18 [4]. The effects of residual linear coupling and dispersion have been quantified. This upgrade represents a key milestone toward achieving the high-intensity heavy-ion beams needed for the FAIR project. The next steps include final engineering design of the new components, hardware procurement, installation and finally beam commissioning in the upgraded transfer line.

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