Research and Diagnosis of Beam Parameters in the SKIF Linear Accelerator

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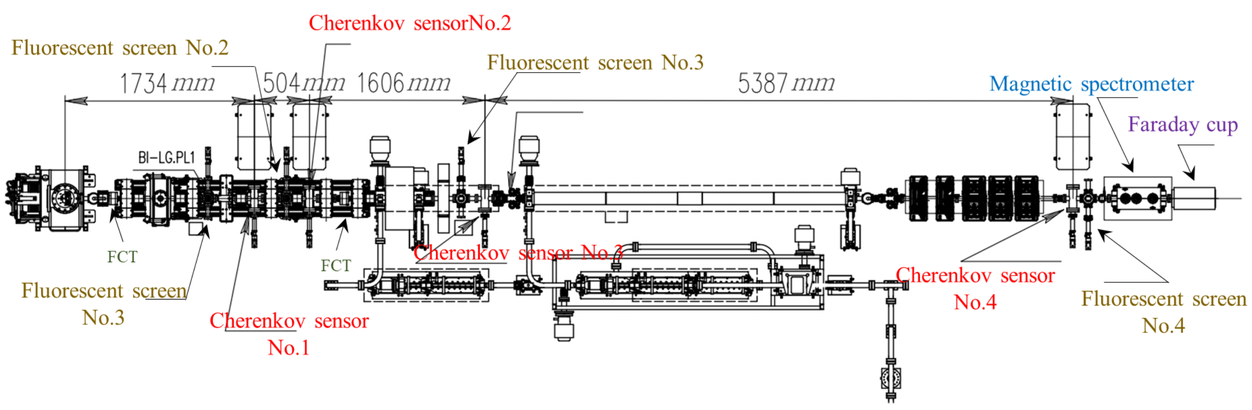
Abstract

The fourth-generation synchrotron light source Siberian Ring Photon Source (SKIF), located in Novosibirsk, Russia, successfully tuned its linear accelerator with the aid of a comprehensive beam diagnostic system. By deploying a designed beam diagnostic system, crucial beam parameters—including transverse and longitudinal dimensions, energy and energy spread, emittance, and current—were accurately measured using Phosphor screens, Cherenkov sensors, a dipole magnetic spectrometer, FCTs and a Faraday cup.

This paper elaborates on the design, operation, and practical applications of these diagnostic devices during the accelerator's tuning process. Further, potential optimizations for these diagnostic methods are explored to provide feasible directions for enhancing the performance of the linear accelerator. These diagnostic tools were essential for the SKIF's successful tuning and will serve as a valuable reference for future accelerator development.

Introduction

SKIF project is a unique project in Russia. Its linear accelerator, part of the injection complex, has parameters that have never been achieved at any other installations operating in Russia. A specially designed diagnostic complex was used to obtain these parameters, and it allowed for successful de-bugging experiments on the linac at a specially designed stand. These devices, detailed in figure below, are positioned at critical locations within the accelerator for precise beam dimension measurement and tuning.

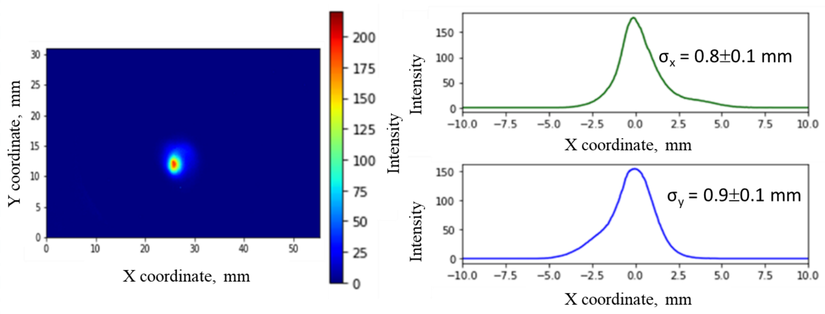


The first acceleration structure and diagnostic equipment layout of SIKF linear accelerator

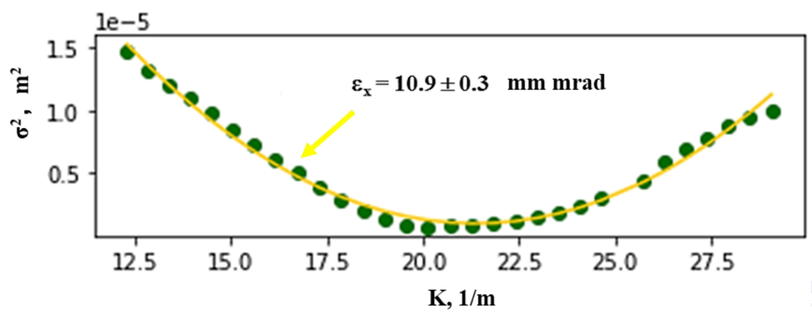
Phosphor screens

- Transverse dimensions & Emittance & Energy

The SKIF linear accelerator's beam transverse dimensions are approximately $\sigma_{x,y} \approx$ 2-3 mm. To obtain a spatial resolution of approximately 0.1 mm, Chromax ceramic or P43 phosphor screens are employed. These Phosphor screens successfully measured the transverse profile of the beam in the vacuum chamber of the accelerator, post-RF cannon, within the grouping channel, post-pre-accelerator, and behind the acceleration structure. The figure above shows a typical measurement.

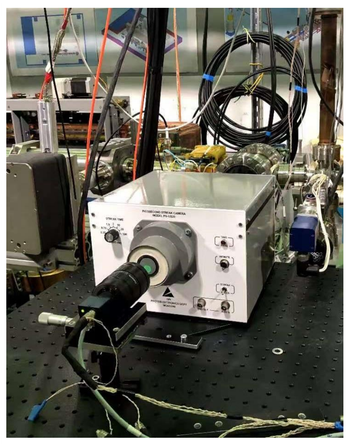


Beam emittance measurements were performed using a phosphor screen, yielding results consistent with design specifications. In addition, the phosphor screen combined with the dipole corrector completes the beam energy measurement after the RF-gun with 5% accuracy.



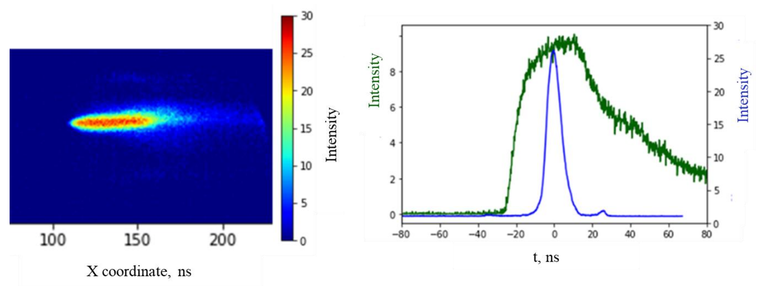
Cherenkov sensors

- Longitudinal dimensions



The Cherenkov sensor, measures beam duration with sub-picosecond resolution. Quartz is suitable for low-energy beams (0.6 MeV), while aerogel is optimal for higher energies (>3 MeV) to avoid total internal reflection. FLUKA simulations optimized the quartz plate thickness to 0.4-0.5 mm for photon emission, with the streak-camera achieving a 3-picosecond resolution. The best resolution obtained was 2.8 picoseconds at the linac output .

The ASTRA package simulation was compared with the measured results to show the dependence of FWHM beam length on the RF gun resonator RF voltage phase, and the results showed good qualitative agreement and showed the potential to reduce the beam length prior to its passage through the buncher, reflecting the non-Gaussian longitudinal characteristics of the beam.

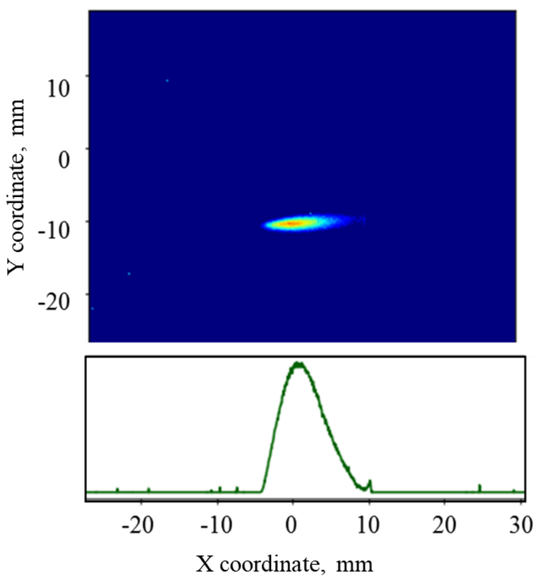


Magnetic spectrometer

- Energy & Energy spread

The magnetic spectrometer measures beam energy and spread from 0.5 to 50 MeV. Beams are deflected and recorded on phosphor screens at 100, 200, and 350 mm intervals from the magnet entrance. The shape and position of the beam impact on the screen allows us to determine the beam's energy and energy distribution.

The third screen captured a 32 MeV beam with an energy spread of ΔE = 1.6 ± 0.1 MeV (FWHM). The accuracy of determining the maximum beam image coordinate is no worse than 0.25 mm, or a resolution of 0.1 MeV for the spectrometer when the third phosphor screen is used. The maximal measured beam energy of linac was 47 MeV that restricted by the power which feed the accelerating structure.

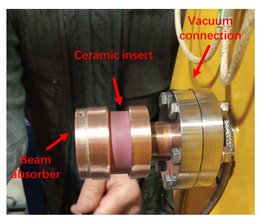


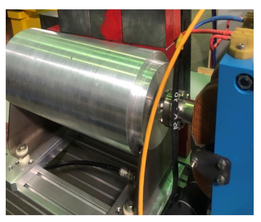
The typical beam image at the 3rd phosphor screen of the magnetic spectrometer

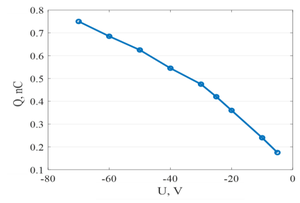
Faraday cup

- Beam charge & beam absorber

A total of two FC are used, each mounted in different locations in the linac, and the charge was calculated by integrating the signal.







Conclusion

The paper describes the range of diagnostics used for commissioning and tuning the linear accelerator at SKIF. These diagnostics were successfully applied to measure the electron beam parameters of the linac and contributed to achieving the designed values for the installation.