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BEAM INSTRUMENTATION FOR LINEAR ACCELERATOR OF SKIF SYNCHROTRON LIGHT SOURCE

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Abstract

A new synchrotron light source SKIF of the 4th generation is under construction at BINP SB RAS (Novosibirsk, Russia). The linear accelerator is SKIF's injector to provide 200 MeV electron beam. The set of diagnostics will be applied for tuning of the linear accelerator and measurements of beam parameters from electron RF gun to output of the accelerator. It includes 8 fluorescent screens for the beam transverse dimensions measurement, 2 Cherenkov probes for the beam duration measurement, magnetic spectrometer with range from 0.6 to 200 MeV, and some beam charge and current measurement devices, as Faraday cup, FCT, BPM along linear accelerator. Numerical simulations of diagnostics elements and results of beam dynamics simulations are introduced in paper. Brief description of the design and parameters of each diagnostics system is presented. Possible scenarios of linear accelerator tuning are also discussed.

INTRODUCTION

SKIF was designed as a fourth-generation synchrotron radiation light source with emittance of 75 pm and energy of 3 GeV [1]. It is expected to be commissioned at 2023, which will allow the start of scientific research as early as 2024. Its injection system is a linear accelerator, which will deliver the electron beam with energy of 200 MeV and beam charge up to 1 nC. The linear accelerator is composed of several main parts, the layout is shown in Fig. 1.

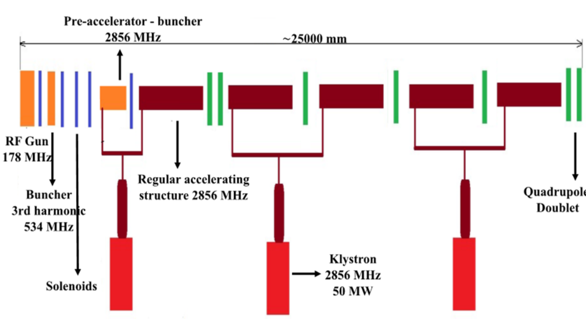

Figure 1: Layout of SKIF linear accelerator.

The beam duration is reduced from 100 ps to 3 ps during acceleration for to get 1% energy spread at the exit of the linac. The main structural parameters of the installation are listed in Table 1 [2]. In order to obtain beam parameters at different stages of construction, operation and maintenance, it is necessary to establish diagnostic system after each section of the accelerator.

The combination of physical and mechanical, electronic and software engineering enables the diagnostic device to be flexibly applied under different working conditions [3]. This article is intended to introduce the diagnostic instrumentation designed for the SKIF linear accelerator. Diagnostics used for the following functions will be discussed: beam transverse distribution measurement, beam longitudinal profile measurement, current charge intensity measurement, beam position monitoring.

Table 1: Parameters of the SKIF Linear Accelerator

Structure	**The main parameters (1 nC mode)**
After the electron RF gun	σ_x= 2 mm, σ_y = 2 mm, σ_z = 40 mm, E = 0.6 MeV
In the bunching channel	σ_x= 2 mm, σ_y = 2 mm, σ_z = 15 mm, E = 0.6 MeV
After the pre-accelerator	σ_x= 2 mm, σ_y = 2 mm, σ_z = 2.3 mm, E = 3.2 MeV
After the 1st accelerating section	σ_x= 2.2 mm, σ_y = 0.6 mm, σ_z = 2.3 mm, E = 50 MeV
At the exit of the Linac	σ_x= 1 mm, σ_y = 0.4 mm, σ_z =1.5 mm, E = 200 MeV

FLUORESCENT SCREEN

A total of eight fluorescent screens are used in the linac to capture information about the beam transverse distribution with energy of 0.6 MeV, 3 MeV, 50 MeV and 200 MeV in different sections of the linear accelerator. The design of the screen is shown in Fig. 2.

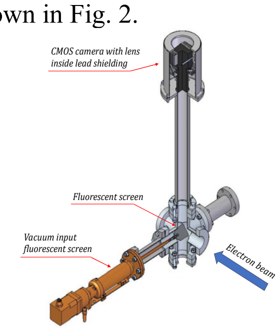

Figure 2: Scheme of fluorescent sensor in SKIF linac.

The screen is made by CHROMOX [4], and the beam image is captured by the CMOS digital camera MANTA

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G-158 [5]. The screen is controlled by a linear actuator CAHB-10 [6]. The CMOS camera is located outside the middle plane and is protected by lead screen.

CHERENKOV SENSOR

Applications of Cherenkov light emitted by the movement of electrons in quartz or aerogel for measurement of beam longitudinal distribution are well known [7]. The limit of Cherenkov sensor temporal resolution depends on the material of radiator (quartz or aerogel) and beam transverse size at entrance of the radiator [8]. The temporal resolution corresponding of beam size in the radiator of 1 mm is about 3 ps for quartz and 1 ps for aerogel.

The scheme of the diagnostic optical system is shown in Fig. 3, which is used to measure three energy conditions (0.6 MeV, 3 MeV, 50 MeV). The minimum photon flux recorded by PS-1/S1 streak camera is about 10^6 ph. [9].

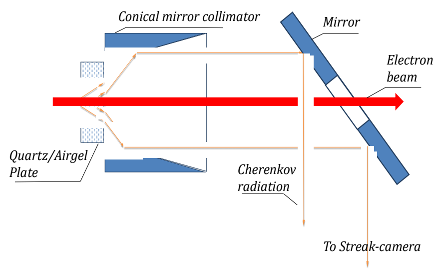

Figure 3: Scheme of Cherenkov sensor for measuring of longitudinal beam profile.

The feasibility simulations are carried out by FLUKA package [10].

Under 0.6 MeV, only quartz (n = 1.46) could be used as Cherenkov radiator. Assuming that 0.6 MeV beam at the entrance of Cherenkov sensor was successfully focused at 1 mm by solenoids, the angular distribution of Cherenkov radiation through different thicknesses of quartz plate was shown in Fig. 4.

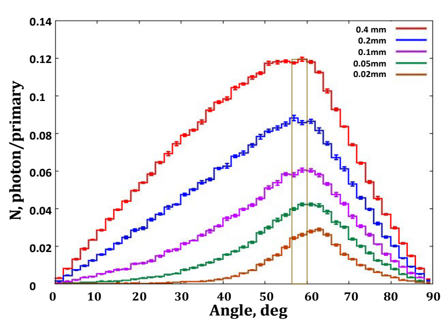

Figure 4: Cherenkov radiation angular distribution of 0.6 MeV electrons beam through different quartz plate.

The results of simulations revealed that the thickness of the quartz plate needs to be limited to 0.5 mm, and the reduction rate of the optical system should be 5 times or greater. It is expected that only 5% of the photon flux could reach the photocathode of the streak camera that is about 2×10^9 particles. In this case, the temporal resolution of this diagnostic is expected to be 3 ps.

Aerogel (n = 1.05) could be used as a radiator to measure 3 MeV, 50 MeV beams. The total photon flux generated by a 5 mm thickness aerogel is equal to $N_{ph} \approx 1.5\times10^{11}$ for a beam charge of 1 nC. The simulated distribution of the photon angle at the exit of the aerogel radiator is shown in Fig. 5. We can still obtain a temporal resolution of about 2~3 ps, which is only restricted by the parameters of the streak camera.

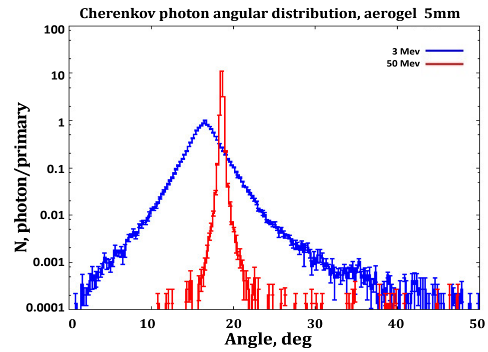

Figure 5: The angular distributions of Cherenkov photons emitted by 3 MeV and 50 MeV electron beam passing through 5 mm aerogel.

SPECTROMETER

The magnet spectrometer consisting of a dipole magnet, fluorescent screen, projection optical system and a CMOS digital camera will be used to measure the energy and energy spread of beam along the linear accelerator [11]. The diagram of the spectrometer is shown in Fig. 6.

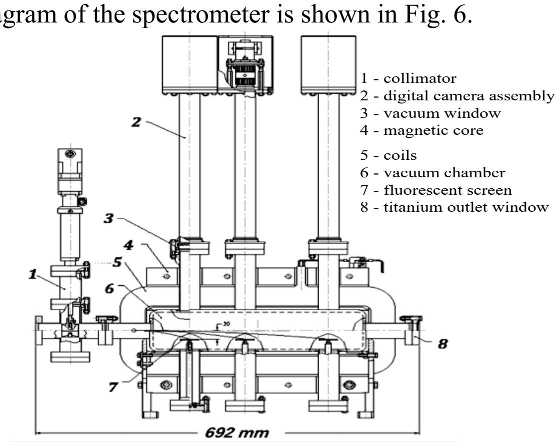

Figure 6: Layout of magnet spectrometer.

Table 2: Calculated Parameters of the Fluorescent Screens of the Magnetic Spectrometer

L, mm	E, MeV	E_{min}, MeV	E_{max}, MeV	B, Gs	E/dx, keV/mm
100	0.6	0.40	0.83	77.86	17.3
200	6	5.22	6.83	129.45	64.5
350	50	45.90	53.67	329.7	287.4
350	200	183.5	214.2	1307	1228

Table 2 shows the magnetic field value, energy range and energy spread at the corresponding measurement position

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and energy on each screen. According to calculations performed by the ASTRA code [12], the spectrometer could measure the beam energy from 0.6 MeV to 200 MeV with an accuracy of about 1%, and measures the beam energy spread with an accuracy of 2-3%.

The FLUKA package is used to simulate the movement of particles in dipole magnetic field and the interaction between particles and materials. Figure 7 shows a typical simulation result of the beam profile at diagnostic window. The results by Fluka and Astra confirm each other.

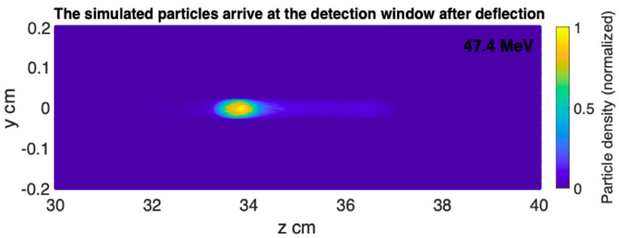

Figure 7: The simulated longitudinal profile of the beam.

BEAM CHARGE MEASUREMENTS

Faraday Cup

Faraday cup is applied for measurements of the electron beam current. The losses of particles in the cup were simulated at 200 MeV beam energy. For 14 cm thickness copper or 7 cm lead, about 5% of beam charge will escape from the exit surface of the absorber with secondary electrons. For the lead and copper absorber with radius of 6 cm and 8 cm respectively, the particles losses on the lateral surface of absorber does not exceed 1%.

Fast Current Transformer

Four FCTs (FCT-CF4"1/2-34.9-40-10:1-UHV) from Bergoz firm will be installed [13]. The signals from these FCTs through LPF with cut-off frequency 50 MHz come to four channels of fast ADC DN2.222-02 from Spectrum Instrumentation (Fig. 8). ADC sampling frequency is 2.5 GHz. Then signal integral in digital form is finding. On base of this integral the beam charge is calculated. Expected absolute accuracy of beam charge measurements is ~5% for beam charge range 1-15 nC, expected related accuracy (or repeatability) of measurements 1-2%.

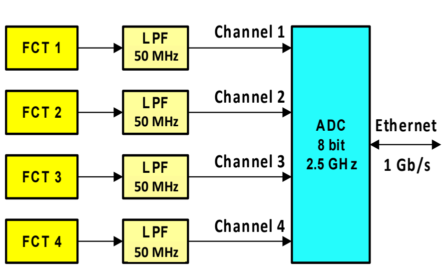

Figure 8: Block diagram of beam charge measurements.

BEAM POSITION MONITOR

The BPM system in the linear accelerator includes 7 electrostatic BPMs and their electronic equipment, which can measure the trajectory after each beam "shot" (Fig. 9). BPM consists of 4 short-circuited at one end striplines with 50 Ohm and 4 vacuum N-type welded connectors. The electronics could measure the beam position with accuracy of 10-20 µm.

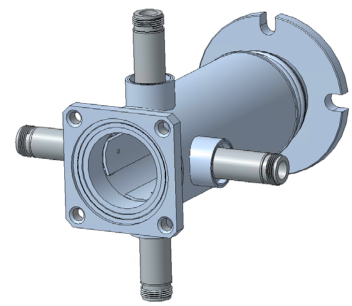

Figure 9: Stripline type BPM.

A functional diagram of electronics for one BPM is represented in Fig. 10. In order to reduce the measurement error caused by the inequality and instability of the transmission coefficients of separated analog channels, a calibration signal is used.

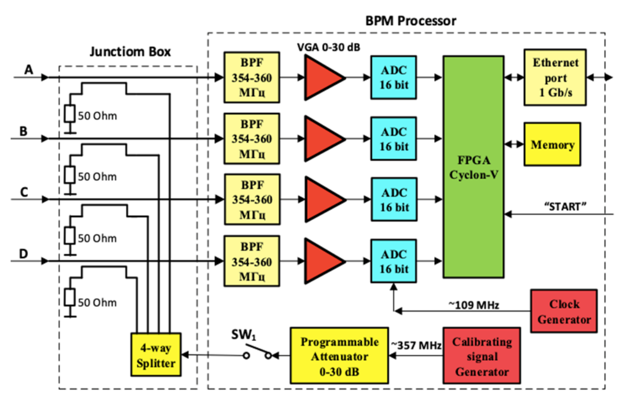

Figure 10: A functional diagram of electronics for one BPM.

CONCLUSION

This article introduces the diagnostics planned to be installed on the linear accelerator at the SKIF. Fluorescent screens was used to measure the transverse distribution of the beam with a spatial resolution of 0.05 $\sigma_{x,y}$=0.15 mm. It is proposed to use the optical diagnostic method to measure the longitudinal beam size, based on Cherenkov radiation, using quartz and aerogel as the radiator. The Cherenkov sensor could operate with a temporal resolution of 2-3 ps. The spectrometer with uniform transverse field could measure energy and energy spread of the beam with 1-3% accuracy in a wide energy range from 0.6 MeV up to 200 MeV. There are two types of instruments used for measurement of beam charge, the Faraday cup with lead as the absorbing material and the FCT, which could measure 200 MeV, 0.3-1 nC beam with an expected accuracy of 5%. Stripline type beam position monitor (BPM) is employed to measure the beam position, and the measurement accuracy of electronic is 10-20 µm.

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