STOCHASTIC COOLING SYSTEM AT NICA PROJECT

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Abstract

Stochastic cooling system is one of the crucial elements for luminosity preservation at NICA accelerator-collider complex. The foundation of main parameters of the stochastic cooling system is provided. The preparatory experimental work for longitudinal stochastic cooling was performed at Nuclotron accelerator. The description of Nuclotron system components, adjustment algorithms and remote control is given.

INTRODUCTION

NICA accelerator-collider complex is under construction in JINR [1]. One of the challenging technologies of the collider project is the stochastic cooling. It is required for beam accumulation and luminosity preservation. Stochastic cooling is developed in Russia for the first time and operational regimes differ from those used before in the world. So before the run of NICA a test channel was put into operation at Nuclotron.

GENERAL SCHEME

Stochastic cooling is a microwave broadband system with feedback via the beam. The working principle is the following: pickup electrodes detect noise from the beam, signal propagates through the system and applies on the kicker. For effective operation signal has to be properly amplified and delayed. If delay and amplification are correctly adjusted one has the reduction of betatron amplitudes in case of transverse cooling or momentum spread in case of longitudinal cooling. General scheme of Nuclotron stochastic cooling system is presented at the figure 1. This system has bandwidth 2-4 GHz and 60 W maximum output power. It consists of pickup with preamplifiers, notch filter, block of switches, variable delay and attenuation and diagnostic devices to maintain different modes of operation, main amplifier and kicker.

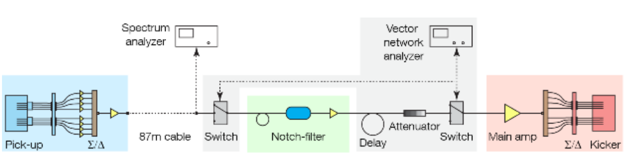

Figure 1: General scheme of the Nuclotron stochastic cooling system.

Pickup and Kicker

Pickup and kicker are HESR type ring-slot couplers which were designed and constructed in FZ Jülich [2]. Pickup is installed in vacuum chamber and has 8 outputs from 8 azimuthal positions around the beam (fig. 2a). Signals from outputs are amplified and can be combined into transverse horizontal, transverse vertical and longitudinal common signals (figure 2b).

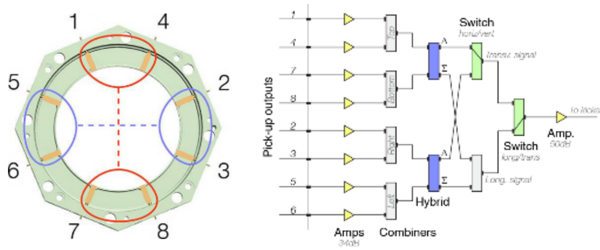

Figure 2: Pickup transverse cross section (left) and commutation scheme (right).

Kicker is the same device as pickup. It has identical commutation scheme with no amplifiers. The difference is that common signal splits to 8 signals at kicker.

Notch Filter

Notch filter (figure 3) receives RF signal from pickup. The signal is modulated by infrared laser and is divided into two lines.

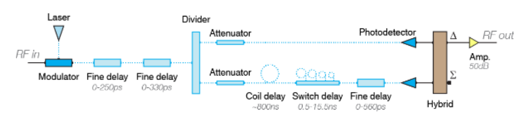

Figure 3: Scheme of optical notch filter.

Part of the signal from the short line passes directly to the output, another part from the long line passes through coil delay, switch delay and fine delay. Each line has photodetector demodulating optical signals to RF at its end. Signals from two lines are combined with 180° phase shift and outgoing signal is enlarged by 50 dB amplifier. To realize time-of-flight method the long line of the filter has to be switched off.

Variable Delay and Attenuation

These simple devices are manipulated by a set of switches. Each switch contacts either short line or modified (delay or attenuation) line (figure 4).

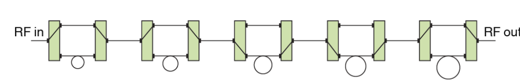

Figure 4: Scheme of variable delay.

Variable delay has 0.5, 1, 2, 4, 8 ns modified lines and range of manipulation 0-16 ns. Variable attenuation has 1, 2, 4, 8, 16, 24 dB lines and range of manipulation 0-55 dB.

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Main Amplifier

For stochastic cooling system it is required to have approximately frequency independent amplitude and phase response. Amplitude and phase response of main 60 W amplifier was measured and the result is given on figure 5. For bandwidth 2-4 GHz amplifier has excellent amplitude response, phase response is good enough, but has to be improved by phase equalizer.

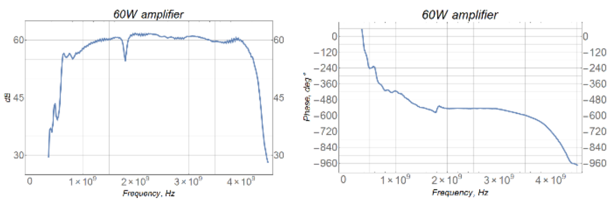

Figure 5: Amplitude (left) and phase response (right) of main 60 W amplifier.

REMOTE CONTROL AND MODES OF OPERATION

While system is in operation it needs to be quickly adjusted and remotely controlled. Thus application for remote control and automatic adjustment was developed (figure 6).

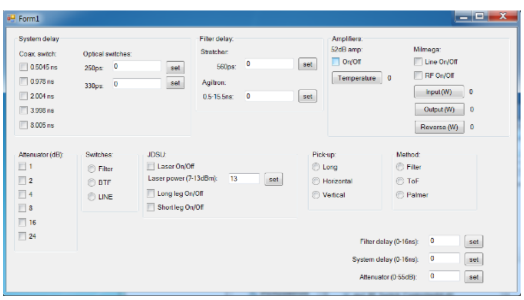

Figure 6: Interface window of the application for remote control and automatic adjustment.

Stochastic cooling system at Nuclotron has 3 modes of operation: filter adjustment, measurement of beam transfer function – BTF (system delay adjustment) and cooling. Commutation between these regimes is provided by block of switches (figure 7).

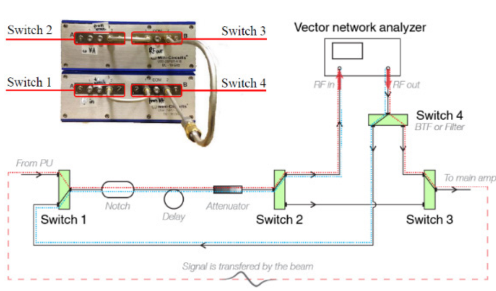

Figure 7: Operational regimes of stochastic cooling system at Nuclotron.

Adjustment in first two modes is supported by network analyzer measurements. In the first mode signal from network analyzer passes only through notch filter, variable delay and attenuation. In BTF mode the signal from the analyzer is transferred via the beam, and returns through the system. In the cooling regime the loop consisting of system components and the beam is closed.

EXPERIMENTAL RESULTS

Nuclotron stochastic cooling system was developed, assembled, adjusted and tested. The momentum cooling of bunched and coasting beam of D^+ and C^{6+} was obtained during several runs at Nuclotron [3]. As an example the momentum cooling of coasting deuteron beam is presented at the figure 8a. The beam intensity was 2×10^9 and energy 3 GeV/u. The RMS momentum spread was reduced by approximately a factor of 2.2 within 480 s. This process of longitudinal cooling was also calculated by solving the Fokker-Planck equation [4]. The simulation and experimental results are in reasonable agreement (figure 8b).

a) b)

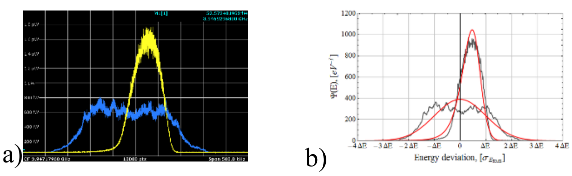

Figure 8: Reduction of beam energy spread: a) experimental result, b) comparison with simulation.

IBS CALCULATION

To preserve luminosity in the NICA collider the stochastic cooling system has to counteract the dominating heating process of intra-beam scattering (IBS). IBS rates calculations were performed in BETACOOL. Structures with β*=35, 70, 100 cm, where β^* is the β-function in collision point, were compared. While horizontal emittance was fixed and equal to 1.1 π mm. mrad., vertical emittance and momentum spread were chosen to match the equilibrium of heating rates between all three degrees of freedom.

If RF voltage is chosen to provide RMS bunch length σ_s=60 cm, then its maximum is less than the project limitation VRF_{max}=1 MV. Bunch intensity was matched in order not to exceed the acceptable betatron tune shift $\Delta Q=0.05$ and the project luminosity $L=10^{27}$ $cm^{-2}s^{-1}$.

The project luminosity in the structure with $\beta^* = 35$ cm is achieved at energy 3 Gev/u and bunch intensity 2.4×10^9. In structures with $\beta^* = 70$ and 100 cm the required luminosity is achieved at 3.2 and 3.4 Gev/u at 1.2 and 1.4 larger bunch intensity respectively. IBS rates for compared structures were calculated considering forgoing data and its values are about equality in the energy range between 3.3 and 4.5 GeV/u. The results of IBS calculation for different structures are presented at figure 9.

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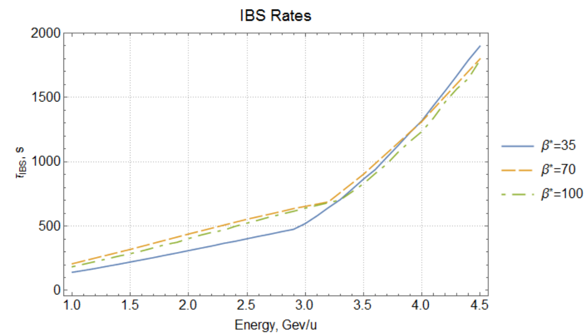

Figure 9: Rates of intra-beam scattering for different structures.

PARAMETERS OF THE COLLIDER STOCHASTIC COOLING SYSTEM

One of the limitations for the stochastic cooling system is the Shottky band overvap in the passband. The passband has to be the widest octave band with no or small Shottky band overlap. The project energy range for stochastic cooling in the collider is above 3 GeV/u. The convenient passband for this energy range is 2-4 GHz.

Another critical parameter is acceptance of the system. To avoid parasitic bunches and particle losses the acceptance of a cooling method must be larger than the separatrix height.

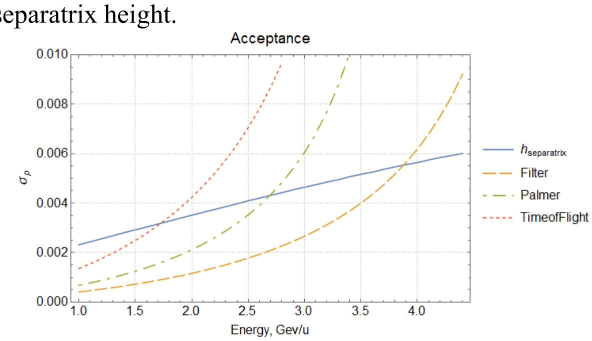

Figure 10: Acceptances of stochastic cooling methods.

In figure 10 it is seen that the filter method does not cover the whole separatrix at energies below 3.9 GeV/u.

We assume that the cooling method is applicable if its rates for the optimal gain is at least two times faster than equilibrium IBS rates.

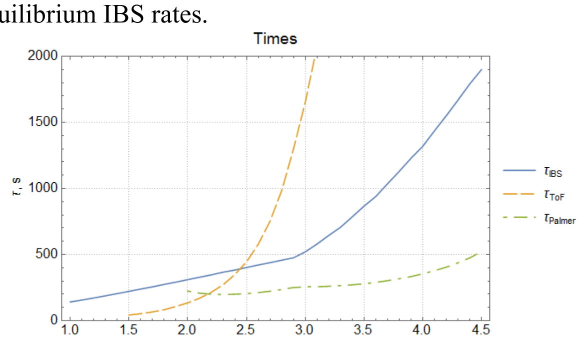

Figure 11: Cooling rates in comparison with IBS rates.

In figure 11 cooling rates for the rest methods are presented in comparison with IBS rates. It is seen that the ToF method does not provide required rates. So the only method which satisfies all conditions is Palmer. The ratios of heat/cool for compared structures is presented in table 1.

Table 1: Comparison of heat/cool ratios for different structures.

E=3Gev/u	β*=35 cm	β*=70 cm	β*=100 cm
IBS/Palmer	2,034152	2,54291	2,464272

CONCLUSION

New developed scheme was set in operation. All system components proved to be reliable and effective. With the developed software for remote control and adjustments the system can be easily operated and adjusted. Coasting and bunched beam cooling was obtained in Russia for the first time. Nuclotron experiments provided the basis for developing a stochastic cooling system of NICA collider and showed appropriateness of HESR type kicker for NICA and FAIR. Based on experience with stochastic cooling at Nuclotron the CDR for the NICA stochastic cooling system had been worked out, development of the TDR is in progress.

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