Optical Notch Filter for the Stochastic Cooling System of COSY

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Abstract

Two cooling methods are installed in the cooler synchrotron COSY. The electron cooler is used for stacking and cooling of proton beams with energies between 45 MeV and 180 MeV. After last year's commissioning the stochastic cooling system became a standard tool for beam cooling in the momentum range of 1.5-3.3 GeV/c. The stochastic cooling pickups also serve for precision measurements of the chromaticity [6]. One advantage of COSY is the possibility to set up different machine settings in a 'supercycle'. Internal experiments can take data below, close at and far above the threshold in one supercycle. The transversal stochastic cooling system was updated using the COSY software timing system to allow cooling in all three experiments. For longitudinal cooling a new notch-filter was fabricated. The delay-line of the notch-filter was substituted by an optical delay line. We will present the characteristics of the optical notch filter and the enhancement of the beam quality for an internal gas target using the longitudinal cooling system with the new notch-filter. In order to use the longitudinal cooling in a 'supercycle' the optical delay line has been further improved. A part of the optical signal path is carried free through an air section. This section is adjusted according to the beam travelling time with the aid of a motor-driven prism.

1 INTRODUCTION

The transversal stochastic cooling system operates in the frequency range from 1 to 3 GHz divided into two bands. [1]. The stochastic cooling has been used for the internal gas cluster target experiment COSY11. The cycle length has been increased up to 1 hour. Less than 10% of the stored protons were lost. The cooling system reached an

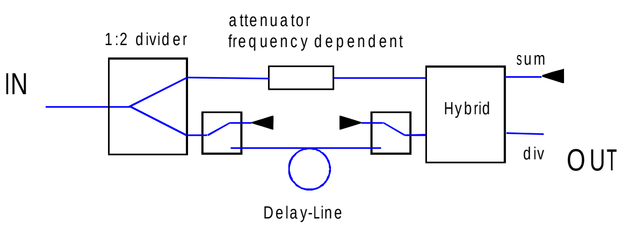

Fig. 1: Notch filter for the longitudinal cooling

equilibrium state after 20 minutes, where the energy loss of the protons through the gas target was compensated by the longitudinal cooling system. The shape of the distribution remains unchanged until the end of the spill [3,4].

The longitudinal cooling was realized by using the vertical band 1 system in sum mode including a simple notch filter (fig. 1) [2]. The attenuator in the short branch compensates the loss of the delay-line especially its frequency dependence. This attenuator is fixed once. There is no remote control of the value and the frequency slope.

2 STOCHASTIC COOLING IN A 'SUPERCYCLE'

The possibility to group up different machine settings within a 'supercycle' is a major advantage of COSY [5]. The transversal stochastic cooling system has been upgraded using the COSY timing system to allow transversal cooling in all settings. The installed programmable delay-lines allow a change of proton momentum from 2.15 to 3.4 GeV/c or with an additional fixed length of 5 m from 1.68 to 2.15 GeV/c in one supercycle with transversal stochastic cooling. Longitudinal cooling in a supercycle needs a system adjusting the length of the delay-line in the notch-filter. Both accuracy and resolution are required to be in the order of $1*10^{-6}$. An envisaged realization using commercial RF components seems to consume too much time and costs. The solution transferring the RF signals into the terahertz region of a laser source was more praiseworthy [3].

3 OPTICAL NOTCH-FILTER

The first version of the notch-filter was fabricated in a similar structure like our coaxial notch-filter. The delay line was substituted by an optical structure (Fig. 2).

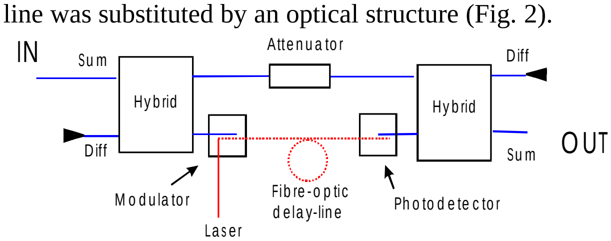

Fig. 2: Optical delayed notch filter

The modulator attenuates the laserlight synchronously to the longitudinal RF signal of the pick-up. The infrared signal is delayed by a fibre optic coil. The RF signal is afterwards reconstructed by the photodetector. The equal phase power divider [2] was substituted by a hybrid

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having a better decoupling between the short and the long branch of the notch filter. The frequency dependence of the attenuation in the optical delayed branch is negligible because the small relative bandwidth required of the optical system is around $3*10^{-6}$ at the RF frequency band of 1-1.8 GHz. Therefore, the RF attenuator in Fig. 2 is now a frequency independent one. Equalizing the attenuation between the short and the long branch of the notch filter is simply fulfilled by regulating the power of the laser light.

The longitudinal cooling was improved by the optically delayed notch filter in the following items:

The notch depths over the whole frequency band exceed values of 35 dB compared to 25 dB of our first RF delayed filter. The dispersion of the optical notch filter can be neglected. Frequency shifts of only 25 Hz relating to the proton revolution frequency were measured at the RF band end caused by small phase deviations between both branches of the notch filter. The dispersion of the coaxial line used for the delay in the coax notch filter is essentially larger.

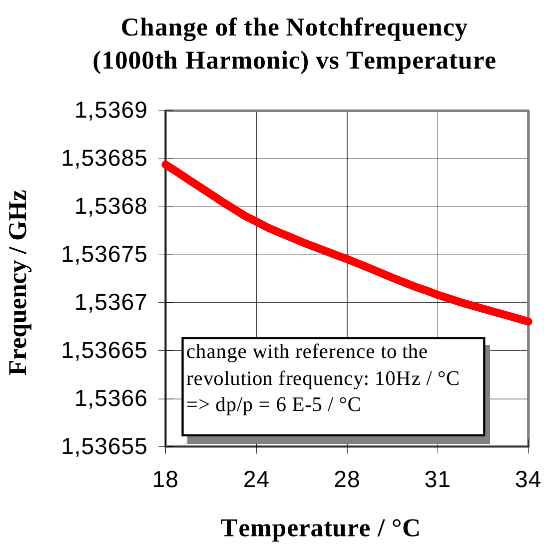

Fig. 3: Temperature behaviour of the optical delayed notch filter

The temperature behaviour of the optical notch filter was measured. Fig. 3 shows the change of the notch-frequency versus temperature. The frequency change is so small that no further steps like the use of a temperature stabilized fibre optic has to be taken [7].

The horizontal Band 1 cooling system was extended by a new path for the longitudinal optical cooling system. Amplitude and phase of this new signal path have been adjusted by automated BTF measurements. The optical notch filter was installed and tested with beam. After several minutes most of the particles are concentrated at the momentum given by the frequency of the notch filter.

Fig. 4 shows the resulting Schottky signal measured at the revolution frequency over 1.5 h.

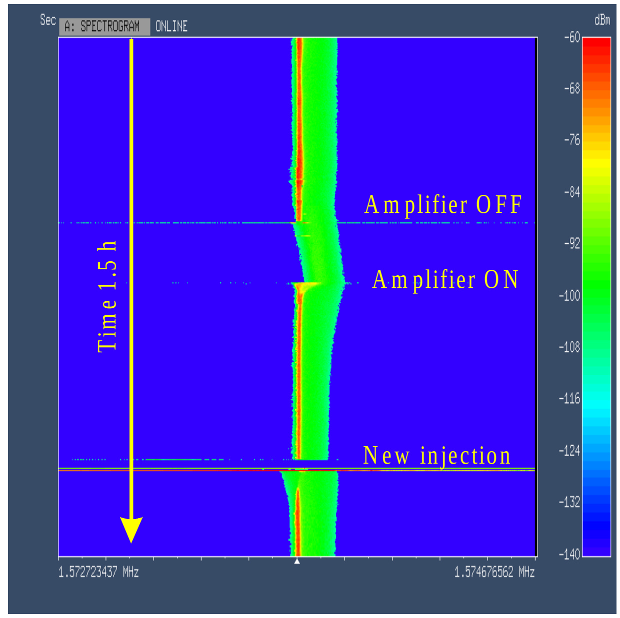

Fig. 4: Longitudinal Schottky scan

When the amplifier of the cooling system are switched off the distribution would be shifted upwards in frequency due to energy loss in the target. The resulting frequency distribution is smaller compared to the old notch filter. Both longitudinal cooling systems (the old notch filter of commercially available RF components and the optical one) were used alternately in a COSY11 run time at different energies.

The cycle lengths were successfully increased up to 2 hours with the aid of the optical notch-filter. After filling the COSY ring for the COSY11 experiment the beam of the cyclotron was used for radionuclide production during these 2 hours.

3.1 Adjustable notch filter

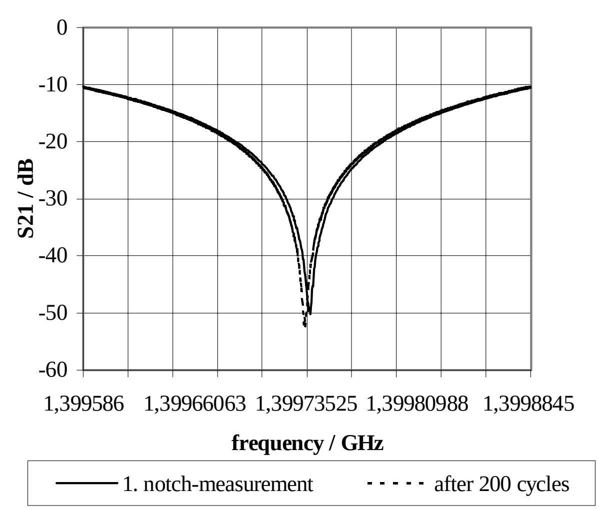

Fig. 5: Accuracy of the repeatability of the adjustable notch filter

We added an adjustable delay line to the notch filter in order to use the longitudinal cooling system in a supercycle. Fig.6 shows the implemented changes of the optical delay line. The system for the fine adjustment was fabricated with a planned adjustable length of about 5m. This length difference is realized by an air section. This section is adjustable according to the beam travelling time with the aid of a motor-driven prism.

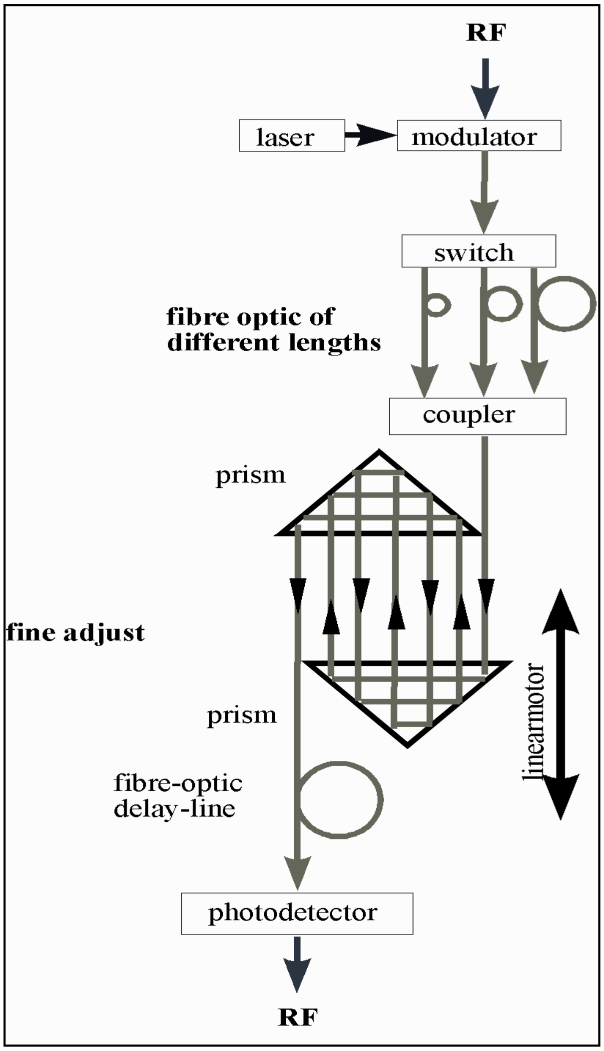

Fig. 6: Adjustable delay line

Fig. 5 presents the first measurements of the adjustable notch filter around the 900th-harmonic of the beam-revolution frequency.

The motored prism was moved 200 times over the moving range and back. 200 cycles are a realistic number for a 1 week COSY11 user run of a cycle length of 1 hour. We reached a reproducibility of $1.5*10^{-6}$.

The temperature changes of the system are now very critical. Small variations of the room temperature caused a displacement of the laser spot after the air-section. The laser light is not coupled completely into the 50µm multi-mode fibre-optic. The amplitude of the demodulated RF-signal decreased and changed the notch depth rapidly to smaller values.

A regulating circuit compensates this loss of the laser-light by adjusting the laser light according to the monitored photo current of the diode in the photodetector. The vertical position of the incoupling collimator is additionally motored with a accuracy of 1 µm. If the available laser power reaches its highest limit the vertical direction will be adjusted to reach the optimal RF-power.

4 CONCLUSION

The fine adjustment of the optical notch filter has been installed in the COSY ring and successfully used in COSY11 user run at 3.2 GeV/c. The experiments can now take data below, close at and far above the threshold with a stochastically cooled beam in one ‘supercycle’. The adjustable notch filter allows longitudinal cooling in the momentum range from 3.4 GeV/c down to 2.6 GeV/c in one supercycle. Different momentum ranges down to 1.5 GeV/c will be available by adding different lengths of additional fibre optics. The signal paths of the transversal cooling systems can be adjusted within a similar momentum range. The beam size of $1*10^{10}$ protons is reduced by a factor of two although the gas target is permanently heating the beam.

5 ACKNOWLEDGMENT

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