FIRST CONSIDERATIONS ON STOCHASTIC COOLING IN COSY JÜLICH

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Abstract

The stochastic cooling (**SK**) in COSY will be performed by SK systems working longitudinally and transversely in the range of 0.5 to 3 GHz. A programm was written for searching SK paths using the well-known optical constraints.
First calculations of the location-dependent numbers of wanted and unwanted mixing were done. The influence of the transition energy was studied. 3 SK paths each had been chosen for 3 energy ranges.
The cooling time for 1.E9 protons will be in the order of magnitude of 10 s.

The SK pick-up and corrector structures are being adapted from the CERN AC structures.
Some simulations of characteristics of filters for the Thordahl SK method were done.
First designs of a cryogenic GaAs-FET amplifier had been made. An amplification factor of 12 dB at 0.5-GHz band-width had been measured.

1. SK systems in COSY

COSY is intended to run in a wide energy range (40 MeV to 2.5 GeV in case of protons) using the ion-optical flexibility for the different operating modes [17]. Therefore, we investigate SK paths that cover most of the desired modes.

The ways in Fig. 1 are chosen using the following procedure:

* Separate ways for horizontal (**H**), vertical (**V**), and longitudinal (**L**) cooling elements both for the Thorndahl filter-cooling [1], [2] method and for the Palmer-Hereward (**P**) cooling method [3], [4];
  this measure eases the decoupling of the H, V and L signals for operation at changing relative particle velocity.

* The cooling system will be divided in groups that are working at low, medium and high energies (around 150, 800, and 1500 MeV).

* MAD calculations were done for the standard working point of COSY of

  Q_H = 3.867 and Q_V = 4.119

  for 3 different quadrupole-field settings for operations without and with dispersion in the target telescope.

* A program "SKW" has been written in order to calculate the qualifications of all possible SKP pairs (SKP: locations for pick-up (PU) and kicker (K) elements).

* 2 paths for stochastic filter momentum cooling with SKPs in the dispersion-free telescope sections were fixed.

The optical input values are taken out of the MAD [6] output file: the my, beta, and dispersion values depending of the polygonial coordinate. The values at the SKPs are automatically interpolated.

The contraints for SK concerning betatron amplitude and phase advance, dispersion (Hereward-Palmer SK) were set suiting [7].
The upper energy limit is calculated using the beam-wave difference delay time. The transit time of the traveling-wave signal from the PU SKP to the K SKP is given by the delay time of all amplifiers in the SK path, a value of 60 ns is estimated for an 130-dB amplifier system, cf. [8].

The qualification of the SK paths concerning wanted and unwanted mixing [7] will be done in a further step.

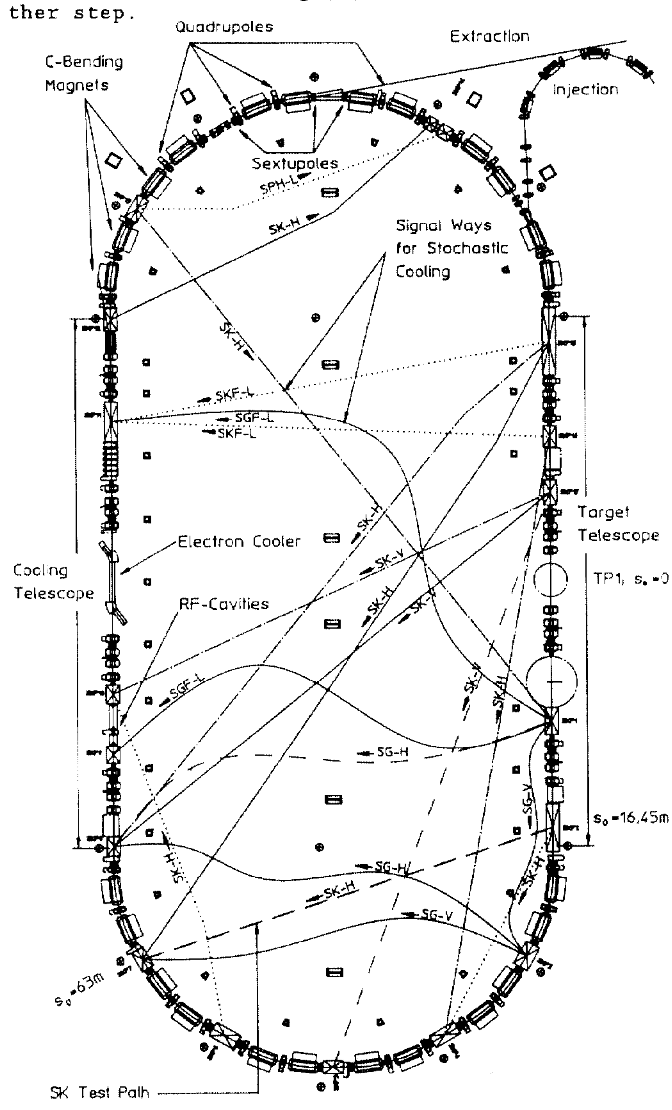

Fig. 1 :
Preliminary
signal ways for stochastic-cooling (SK)
and active beam-feed-back systems (SG) :

SKF:	Thorndahl-cooling method	- H: horizontal
SPH:	Palmer-Hereward cooling	- V: vertical
SGF:	filter feed-back system	- L: longitudinal

s_0 = 16.45 m : test-path PU location,
s_0 + s = 63 m : test-path K location.

The working-frequency ranges will be between 0.5 and 2 GHz corresponding to the above energy ranges. The upper limit is given by the various cut-off frequencies of E, H, EH and HE waves in the beam-envelope components.

2. Estimation of mixing numbers in COSY

Special interest lies in the knowlwdge of the energy range in that SK is expected to be most effective. Furtheron, the ion-optical flexibility makes necessary to investigate the influence of the magnet settings on the cooling time. We here analyse the dependence of the mixing numbers on the focusing parameters for the SK test path given in Fig. 1.

By definition, the mixing number is the number of turns that a particle having the momentum $p + \Delta p$ needs to gain a time difference equal to the sampling-time window T.

The time differences Δt and $\Delta \hat{t}$ from PU to PU and PU to K elements can be calculated via Δs and $\Delta \hat{s}$ being the corresponding path length differences. The path lengths from PU to PU and PU to K locations of a particle following the central orbit are called s and $\hat{s}$ and the corresponding flying times t and $\hat{t}$. The path lengths of the off-momentum particle trajectory are calculated by integration along s according to [9]. The path length differences may easily be calculated if one assumes that the off-momentum orbit is close to the reference orbit. This leads finally to the first-order expression

$$\Delta t / t = - \delta / \gamma^2 - \frac{1}{s} \left[R_{51} x_0 + R_{52} \theta_0 + R_{56} \delta \right] .$$

The matrix elements R_{mn} for PU-to-PU paths (or PU-to-K paths for the values denoted by ^) were calculated by means of TRANSPORT [10] runs. The beam dimension in the PU device is given by the horizontal extension x_0 and the divergence θ_0. The relative momentum spread is denoted by δ. Notice that the energy dependence of Delta t is determined by the kinetic gamma.

In Fig.2, we show as an example the mixing ratios M/2T and $\hat{M}/2T$ for the PU-to-PU and PU-to-K test SK paths as a function of the proton momentum, $(\Delta p)/p = 0.1$ %. The calculations were done for the above working point and a dispersion $D \simeq -10$ m at TP 1. γ_{tr} here takes on the value of 2.4.

The mixing ratio M/2T from PU to PU location ($s_0 = 16.45$ m) exhibits a pole where the time difference $\Delta t \to 0$. Therefore, no mixing occurs for protons of 2.3 GeV/c. The singularity is mostly determined by the matrix element R_{56} according to the above equation. R_{56} is approximately given by the horizontal tune in COSY (circumference of $s_C = 183.47$m) :

$$\gamma_{tr}^2 = - s_C/R_{56} \simeq (Q_H - 2)^2 .$$

The mixing ratio $\hat{M}/2T$ from PU ($s_0 = 16.45$ m) to K location ($s_0 + s = 63$ m) is similar in slope and also has a pole near 2.3 GeV/c. So, we find the approximate relation for $p < 2$ GeV/c

$$M \simeq \hat{M} * s / s_C \simeq 0.25 \hat{M} .$$

Fig. 2 also shows the sensitivity of $\hat{M}$ on the matrix elements R_{51} and R_{52}. Neglecting these elements results in a shift of the singularity down to ~ 1.3 GeV/c. Neverless, the deviation is of the order of 10 % for $p < 0.8$ GeV/c. The influence of R_{51} and R_{52} on M is less pronounced up to 1.5 GeV/c (not demonstrated here).

Additionally, we mention that the number M calculated for $s_0 = 16.45$ m agrees with M in case of $s_0 = 0$ within 10% up to 1 GeV/c (not shown here).

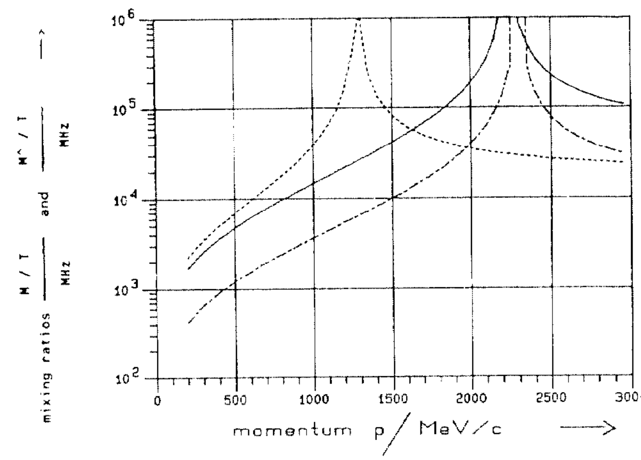

Fig. 2:
Mixing numbers normalized to the sampling-time window T vs. proton momentum [$(\Delta p)/p = 0.1$ %] calculated using transport-matrix elements R_{51}, R_{52} and R_{56} :
_._: M from PU to PU at position $s_0 = 16.45$ m,
___: $\hat{M}$ from PU ($s_0 = 16.45$ m) to K ($s_0 = 63$ m),
...: approx. $\hat{M}$: R_{51} and R_{52} neglected.

Cooling times may be estimated according to [7]. Table 1 shows the results using a value of $1/2T = 500$ MHz (nearly equating to the SK-system bandwidth), a particle number of $N = 10^9$ and a amplitude noise-to-signal ratio of $u = 3$. It is assumed that the optimal gain

$$g_0 = (1 - 1 / \hat{M}^2) / (M + u)$$

is realized. Further investigations are in progress.

Table 1:
Cooling times τ_0 and optimum gain factor g_0 vs. momentum of protons for PU (K) position of $s_0 = 16.45$ m ($s_0 + \Delta s = 63$ m); the sampling-time window is choosen via $1/2T = 500$ MHz

p / MeV/c	200	400	600	800	1000
τ_0 / s	17	9	10	11	14
g_0	0.19	0.24	0.21	0.18	0.15

3. SK tanks in COSY

The requirements for the SK tanks in COSY are most similar to that for the CERN AC ring [11], [12] compared to the other cooler rings. These requirements are

* frequency band width of about 1 octave,
* high-sensitive beam-interaction structures,
* changeable beam-interaction structures,
* remotely changeable beam-structure distance,
* low noise of structures and amplifiers,
* small beam-coupling impedance outside the SK-frequency range,
* UHV compatibility.

The major points of adapting the AC structures to COSY are

- change of the beam-structure distance in order to adapt to the smaller beam dimensions in COSY,
- adapting the phase velocity to the beam velocity in COSY (0.283 c to 0.962 c, AC: 0.967),
- small electrode width for low-emittance beam,
- possibility of stepping the tank length in order to match the space restrictions.

4. Cryogenic amplifier for COSY

The major specifications for the preamplifiers are the linearity of phase within $\pm$ 10 ° and a noise figure $\leq$ 0.8 dB. The latter will be met for a reasonable band width using FET amplifiers cooled to about 20 K as realized in the CERN AC ring.

A first amplififier was designed using the programs "SPICE" [13] and "MINUIT" [14]. A 17-element FET model similar to [15] had been used. The input and output impedances of the FET (Mitsubishi GaAs MES-FET MGF 1412) were transformed into values nearby 50 Ohm using also cooled double-stub tuner circuits. Thereby, a compromise between power match and noise match has been choosen. The cooled amplifier circuit is shown in Fig. 3. An amplification factor of about 12 dB in the middle of a 3-dB range of 1.25 to 1.75 GHz was measured.

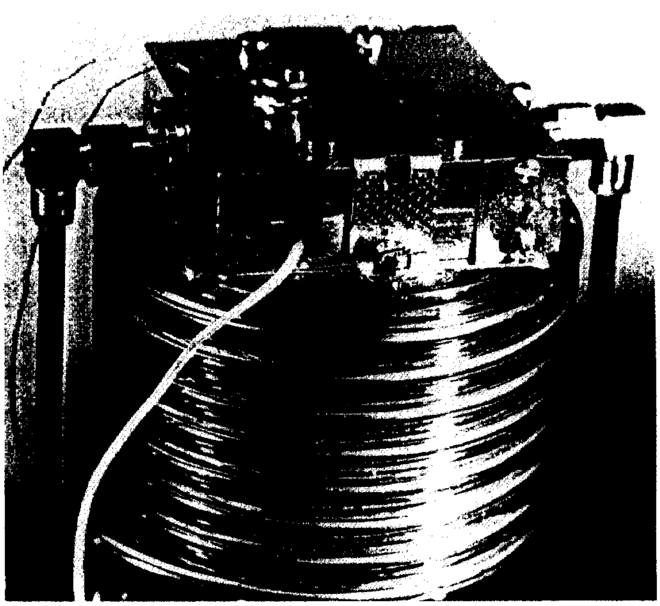

Fig. 3 :
FET amplifier in the center of the cryopump.
(scale 0.8 : 1)

5. Filters for momentum SK

Two kinds of comb filters (stub filter and bridge filter [2], [16]) for the Thorndahl-cooling method were juxtaposed concerning the dispersion of the damping poles. This dispersion is mostly created by the following items :

- skin effect of the filter transmission lines,
- irregularities in the cross sections of the lines,
- parasitic elements of fittings and couplers,
- temperature effects.

The first SPICE calculations and measurements in the COSY specific frequency range have shown that the compensation of the dispersion in the bridge filter might be easier to realize.

6. Acknowledgements

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