The Stochastic-Cooling System for COSY-Jülich

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Abstract

The stochastic-cooling system is under development. Cooling characteristics have been calculated. The tanks are similar to those of the CERN-AC. But the COSY parameters have required changes of the tank design. Active RF components have been developed for COSY. Measured results are presented.

I. OVERVIEW OVER THE SYSTEM

The cooling in the Cooler Synchrotron COSY [1] will work in the ranges: Band I: 1 to 1.8 GHz, Band II: 1.8 to 3 GHz. The system allows cooling in the energy range of 0.8 to 2.5 GeV. A parameter list is given in Tab.1.

There will be separate systems for both transverse planes (Fig.1). The longitudinal cooling will be performed using Thorndahl filters in the sum paths added to the transverse RF-signal processing.

Different cooling paths are envisaged for low and high energies during the test operation. A band-I cooling path will be built as a first step. The diagonal ways (Fig.1) will be used in the nominal operation phase.

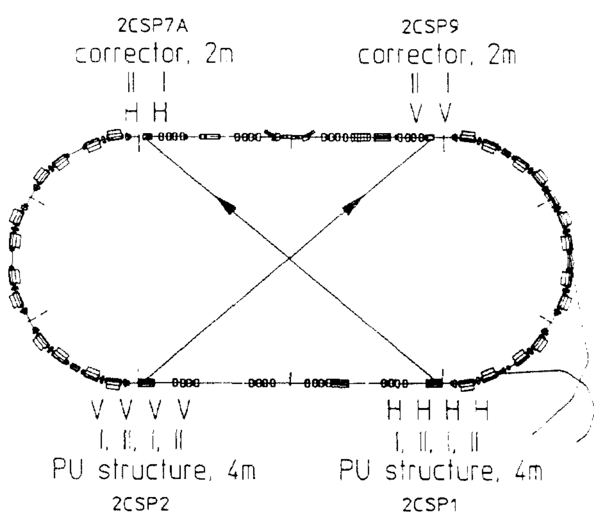

Fig. 1: Stochastic-cooling paths in COSY for nominal operation mode
H (V) : 1-m section of horizontal (vertical) cooling tank;
I,II : Band I: 1 to 1.8 GHz, Band II: 1.8 to 3 GHz.

The time required for transverse cooling from emittances of 5 π mm mrad to about 1 π mm mrad for 10^{10} protons at energies > 1.5 GeV will be in the order of 30 s. The signal-to-noise ratio and the variable power gain of the system allows cooling times of about 1 s for $1 \cdot 10^8$ stored protons. Similar times will be necessary to reduce the longitudinal phase space by a factor of about 3.

II. THEORETICAL INVESTIGATIONS

The cooling parameters have been calculated using the Fokker-Planck equation [2], including an equilibrium emittance [3], and taking hardware formulae corresponding to [4], [5]. The model has been verified using CERN-AC data.

The diagonal ways (Fig. 1) provide small antimixing in the energy range of 0.8 to 2.5 GeV at the given working point. The resulting phase errors are also tolerable over the whole RF band (± 20 - 30 deg.). The transition energy (1.15 GeV) can be shifted if a shorter cooling time is required for experiments around 1 GeV using proton numbers N in COSY of $N > 10^9$. Further, the beam can be heated longitudinally in order to reduce the cooling time if the experiment tolerates the increased longitudinal phase space. The overall power gain of the cooling chain has been optimized for minimum transverse cooling times for $10^8 \le N \le 10^{10}$. The cooling rates will be constant for $N \le 10^8$, and will be proportional to N for $N \ge 10^{10}$.

The cooling times listed in Table 1 are given in the case of operation of band-I and band-II systems. The expected cooling times are longer by a factor of about 3 during the beginning phase (band I only). The longitudinal cooling times in Table 1 have been calculated under the assumptions that the sum signals of both horizontal and vertical cooling systems are combined and that the accuracy of the delay time is better than 50 ps.

III. MECHANICAL TANK DESIGN

Figure 2 shows a partial view of a stochastic-cooling tank. Many of the tank details are being adapted from the CERN AC tanks [6], [7]. The differences of COSY and AC:

- beam parameters (emittances, energy),
- mechanical and space conditions in the ring,
- cooling-frequency ranges

have caused changes concerning the following items:

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Table 1: Stochastic Cooling in COSY Jülich

kinetics				
kinetic energy	T /GeV	0.85	1.50	2.50
momentum	p / GeV/c	1.52	2.25	3.31
rel. mass factor	γ	1.91	2.60	3.66
rel. proton velocity	β	0.85	0.92	0.96
transverse stochastic cooling				
total emittance before cooling	ε_0 / π mm mrad	10	5	5
total emittance after cooling	ε_0 / π mm mrad	1	1	1
cooling time for 10^8 p	$t_{transv.}$ / s	2	1	1
cooling time for 10^{10} p	$t_{transv.}$ / s	30	50	25
longitudinal stochastic cooling				
total mom. spread before cool.	$\Delta p/p$ / 10^{-3}	1.0	1.0	0.5
total mom. spread after cool.	$\Delta p/p$ / 10^{-3}	0.4	0.4	0.2
cooling time for 10^8 p	$t_{long.}$ /s	1	2	2
cooling time for 10^{10} p	$t_{long.}$ /s	10	15	20
ion optics				
orbit length	s_{orbit} /m	183.5		
working point	$Q_{hor.}$ / $Q_{vert.}$	≈ 3.37/3.39		
focussing in bending sections	(horizontal plane)	D-F-F-D		
transition energy	$T_{trans.}$ / GeV	1.15		
transition mass factor	$\gamma_{trans.}$	2.22		
momentum spread at 40 MeV (unbunched)	$\Delta p/p$ /10^{-4}	± 23		
frequency ranges				
frequency range band I	f_I / GHz	1.0 - 1.8		
frequency range band II	f_{II} / GHz	1.8 - 3.0		
tank mechanics				
beam aperture minimum	$w_{min.}$ / mm	20		
beam aperture maximum	$w_{max.}$ / mm	140		
duration of moving cycle	$t_{up/down}$ /s	3		
lifetime of mech. components	n_{cycle}	10^6		
length of tanks	l_{pickup} / l_{kicker} / mm	4355 / 2355		
tank section length	$l_{section}$ /mm	2050		
length of coupler support bar	$l_{support}$ / mm	1950		
inner diameter of tank	d_{tank} /mm	500		
beam pipe diameter	$d_{beam\ pipe}$ /mm	150		
temperature of bars	T_{pickup} / T_{kicker} /K	25 / 300		
water cooling of kicker tanks	P_{water} /kW	1		
vacuum on beam axis	p_{vacuum} / nPa	10		
pickup refrigeration				
temp. of cryo stages	T_1 / T_2 / K	45 / 25		
heat input (cond., radiat.)	P_1/P_2 /W	43 / 6.5		
cool. power (4 RG 580)	P_{c1}/P_{c2} / W	240 / 20		
cooling down time	t_{cool} / h	≈40		
tank RF-components				
beam coupling structure		stripline coupler		
charact. impedance	R_W / Ω	50		
pickup RF length (bands I+II)	l_{pickup} / mm	3840		
kicker RF length (bands I+II)	l_{kicker} / mm	1920		
structure section length	$l_{structrure}$ / mm	960		
RF feed throuhgs per section	n_{FT}	8		
couplers per feed through	n_{cI} / n_{cII}	6 / 8		
dimensions of couplers	$(b \cdot h)_{I/II}$	20 · 32 / 20 · 22		
distance of couplers to beam axis	$d_{c\to b}$ / mm	10 → 70		
RF signal processing				
noise temp. of strip terminations	T_N / K	25		
noise temp. of preamplifiers	T_{N_pre} / K	50		
temp. of preamplifiers	T_{pre} / K	300		
location of preamplifiers		outside of tanks		
total amplifier gain	g_{amp} / dB	150		
tolerance of total gain	Δg / dB	2		
signal delay time of amplifiers	t_{amp} / ns	30		
signal delay time of filters	t_{filter} / ns	30		
tolerance of total delay time	Δt / ps	50		
power per kicker feed through	P_{FT} / dBm	48		
total peak power (H+V+L)	P_{tot} / dBm	63		

- single electrodes instead of super-electrodes,
- size and number of electrodes,
- range of distance between beam and electrodes,
- geometry of movable electrode supports,
- drive of movable electrode supports,
- tank lengths,
- division of tank sections in 1-m subsections for the 2 RF bands,
- arrangement in the RF-feed-through domes,
- steps of signal combining within the tanks,
- cryogenic cooling power.

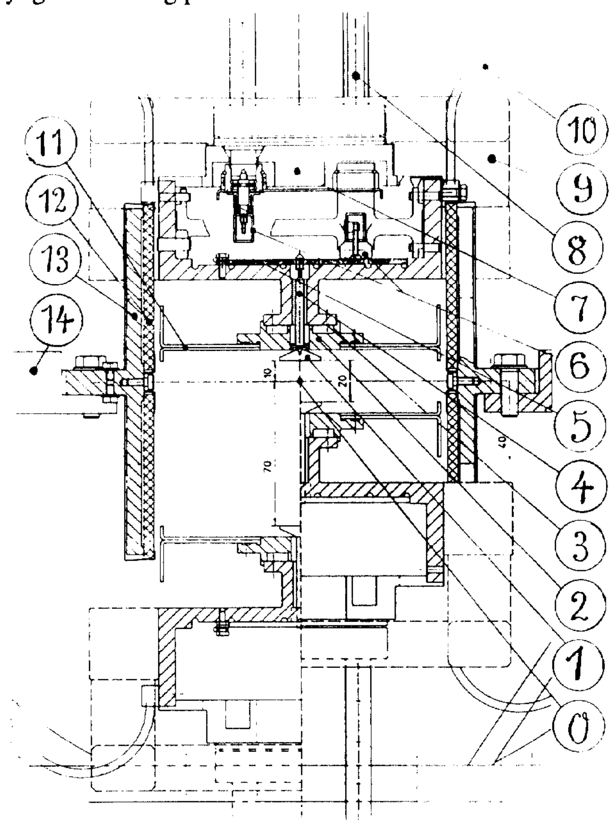

Fig. 2: Stochastic-cooling tank, partial cross-section view around the beam. Three quadrants show the arrangement for the cooled beam; The lower left quadrant indicates the case of uncooled beam.

0: beam center,
1: stripline coupler,
2: stripline-coupler fixing plate,
3: movable support bar,
4: 50-Ohm transmission line,
5: power-combiner/splitter board,
6: connectors to 5, intermediate lines (rectangular coaxial), connectors to 8,
7: traverse for coaxial lines,
8: coaxial line connected to movable stripline,
9: support-bar pivot connected to actuating rams,
10: heat-conducting band (pickup only),
11: RF screening sheets,
12: ferrite tile for attenuation of waveguide modes,
13: ferrite-tile support bar, springs for fixing the tiles,
14: fixed ferrite-bar pillar.

The PU structures will be cooled down to ~ 25 K using the cryopanels of two-stage Gifford-McMahon He cryopumps [8]. The corrector tanks will be similar to the PU tanks. But water cooling will be used instead of He cooling. The modularity of the electrode support allows the construction of 2 m tanks having 1 m of band-I and band-II structure each. The vacuum requirements of COSY (10 nPa) will be fulfilled applying additional cleaning and pumping technics. A large part of the design work of the cooling tanks has been performed up to now. So, the first tanks will be constructed previously during 1992.

IV. RF-SIGNAL PROCESSING

The signals of the single electrodes will be combined for electrode numbers corresponding to 1/4-m PU structure. The further combination steps must be outside the cooling tanks to allow the large energy range of 0.8 to 2.5 GeV. That results in a number of RF vacuum feed-throughs of 8 per 2-m electrode support bar.

2-stage Wilkinson hybrids will be used in the power-combining/dividing networks in order to get the required band-width (2-way and 3-way hybrids). The signal of each RF vacuum feed-through will be preamplified in a low-noise HEMT amplifier. Prototypes operating at room temperatur have been developed for both RF bands. The following characteristics of the band-II preamplifier have been measured (the band-I values are slightly more advantageous):

- noise figure 0.7 dB, corresponding to 50 K, ripple ± 1 dB,
- input return loss > 11 dB,
- amplification gain ~ 30 dB, ripple ± 1 dB,
- output return loss > 11 dB,
- group delay 0.9 ns, ripple ± 0.15 ns.

The intermediate-level electronic components are not separated in 2 RF bands.

A total gain of all amplifiers of 150 dB is foreseen. Digitally controled attenuators will enable to minimise the cooling time for the actual number of protons. Filtering, gain and phase equalization will be done at levels around 0 dBm. Ferrite tiles and resistively coated ceramic tubes will avoid wave propagation in the beam pipes.

Prototypes of 1-to-3-GHz components have been fabricated for COSY:

- low-power amplifiers,
- medium-power amplifiers,
- digitally controled attenuators.

The following global characteristics have been measured:

- input return loss > 11 dB,
- amplification gain ~ 30 dB or attenuation 0 ... 33 dB, ripple ± 1 dB,
- output return loss > 11 dB,
- group delay ~ 1 ns, ripple ± 0.15 ns.

The power amplifiers will be built in 2 RF bands.One driver module will provide the power for 2 end-stage modules. Each end-stage module will have a nominal peak power of 35 W. The output of 2 modules each will be combined and fed into one RF feed-through of the kicker tanks. Design work for band-I and band-II end stages has been made (2 FETs NE345L-10B each). Power gains of the end stage of 9 dB and 5 dB have been calculated. The characteristics have been examinated for a band-I prototyp.

A complete prototype RF-signal path will be constructed previously during 1991.

V. ACKNOWLEDGEMENTS

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