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THE LEAR STOCHASTIC COOLING SYSTEM, PRESENT AND FUTURE

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ABSTRACT : To date stochastic cooling in LEAR has worked at momenta between 600 MeV/c and 200 MeV/c, and some results have also been obtained at 100 MeV/c. Special systems will be necessary in the future to work more efficiently at 100 MeV/c and possibly below. In addition, new cooling loops have to be foreseen for energies well above 600 MeV/c e.g. to work in conjunction with internal target experiments. The implementation of these new systems will be discussed in the light of special hardware and performance problems for ultra-low as for relativisitc beam velocities.

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ABSTRACT : To date stochastic cooling in LEAR has worked at momenta between 600 MeV/c and 200 MeV/c, and some results have also been obtained at 100 MeV/c. Special systems will be necessary in the future to work more efficiently at 100 MeV/c and possibly below. In addition, new cooling loops have to be foreseen for energies well above 600 MeV/c e.g. to work in conjunction with internal target experiments. The implementation of these new systems will be discussed in the light of special hardware and performance problems for ultra-low as for relativisitc beam velocities.

The present stochastic cooling system covers the range from 600 MeV/c to 200 MeV/c, i.e. from 2 to 0.8 Mhz in revolution frequency. In order to satisfy the demands of both internal target experiments, which require high energy stochastic cooling to counteract the beam blow-up caused by the target, and ultra-low momentum operation, where cooling is essential for efficient deceleration and beam manipuliation, a large amount of new hardware is needed.

The wide range of revolution frequencies that have to be covered (3.6 to 0.2 Mhz) means that different solutions to the problems posed at the different momentum ranges will have to be adopted.

The existing cooling systems are outlined in Table 1 and Figure 1. Figures 2 and 3 give an idea of the performance obtained to date. To extend the present methods to higher momenta does not pose any severe technical problem, however recent tests at 100 MeV/c indicate that new ideas will be needed below 200 MeV/c.

Table 1 : PRESENT SYSTEMS

	Longitudinal	*Vertical*	*Horizontal 1*	*Horizontal 2*
Momenta (MeV/c)	*609,309/200*	*609,309,200/100*	*609,309,200*	*100*
Pick-ups	*24 gap & combiner*	*8 loops pairs combiner /T.W.*	*12 loops pairs*	*12 loops pairs trav. wave*
Amplifier & termination	*Room temperature*	*Room tempera-ture /cryo.*	*Room temperature*	*Cryogenic*
Kicker	*8 gaps*	*1 gap*	*1 gap*	*1 gap*
Band (MHz)	*20 - 300 / 15 - 200*	*50 - 500 / 50 - 200*	*50 - 500*	*50 - 200*

The special problems for low momenta are outlined below :

1. Signal Strength. The beam current falls off proportionally with β, therefore the signal to noise ratio worsens. Instead of using standard "combiners" to sum the loop coupler signals, the coupler plates can be connected in travelling wave mode., i.e. summed in series, where the

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phase velocity of the summed signal to the next loop is equal to the beam velocity. For the ideal case, the signal power now increases as the square of the number of loops, instead of linearly, as for the parallel combiners. In addition cryogenic amplifiers will further reduce noise levels.

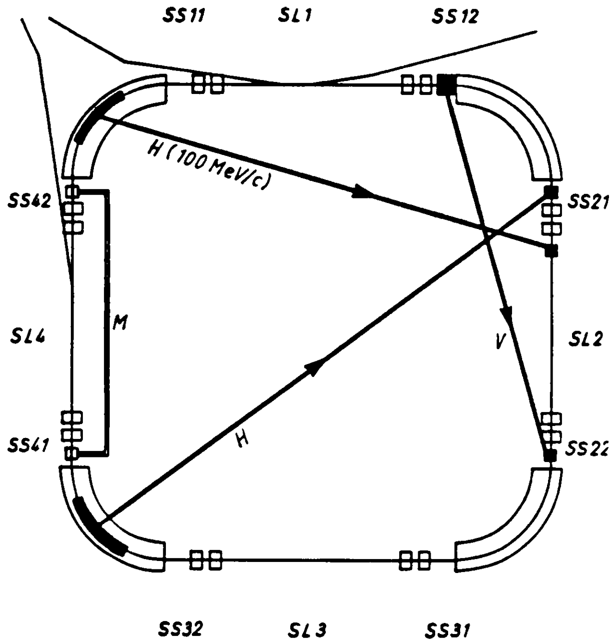
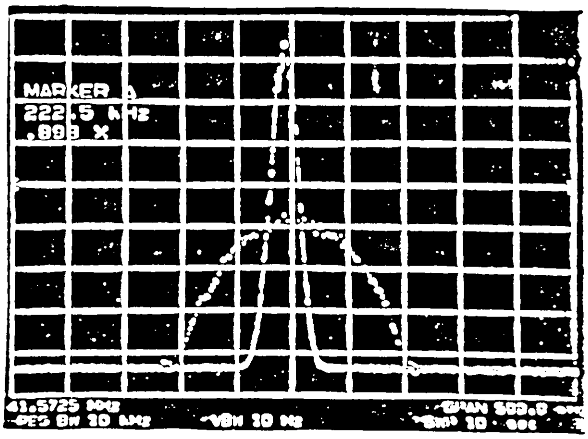


Figure 1 : Present cooling system (600-100 MeV/c).

For ultra low momenta (60 MeV/c and below), instead of using summed loop coupler signals a specific meander pick-up, with similar travelling wave properties, is proposed, along with a helical line pick-up for longitudinal signals. See ref. 1.

Figure 2 : Momentum cooling at 609 MeV/c.

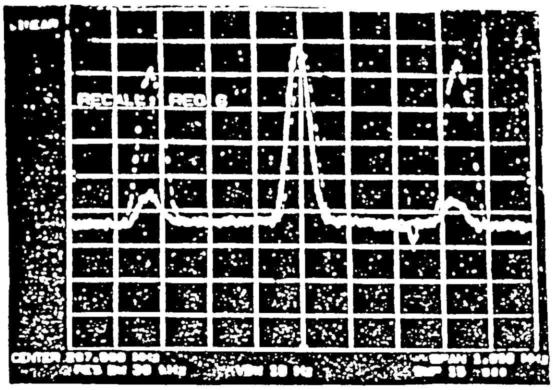


The picture displays the spectral density of the beam "Schottky"-noise current near the 20th harmonic of the revolution frequency. Such "longitudinal Schottky scans" are obtained by spectral analysis of the noise signal induced by the coasting beam on a high sensitivity current pick-up device. These scans may be interpreted as representing the square - root of the particle density vs. momentum.

⟶ *During 3 minutes of cooling the momentum spread of 3E9 particles is decreased by a factor 4! (Picture taken during the operation of LEAR in 1985).*

2. For high momentum a long cooling path is needed as the beam velocity is high, but as the beam momentum decreases, this long flight path leads to undesirable mixing between the pick-up and the kicker.

Figure 3 : Horizontal cooling at 609 MeV/c.



The picture displays the spectral density of the beam "Schottky"-noise, detected by a position pick-up. The central band, the harmonic n = 100 of the revolution frequecy, is visible as the beam is not completely centered at the position pick-up. The right and left bands are the sidebands (98 + Q)f_0 and (103 - Q)f_0 where the betatron tune Qh = 2.3. The hight of these bands is proportional to the rms betatron amplitude of the beam particles. Substracting signal and electronic noise (base line of signal) in square one finds a decrease of amplitude by a factor of about 2.5 . 5 min of horizontal cooling for about 1E9 antiprotons.
⟶ Emittance decrease by 2.5^2 .

The mixing time is given by the difference in arrival time at the kicker δt, where :

$$\frac{\delta t}{t_r} = \eta \cdot \frac{L}{2\pi R} \frac{\Delta p}{p}$$

L = distance from pick-up to kicker.

One needs :
δt < useful length of the correction pulse ≈ 1/4 x f_{max}, f_{max} = upper frequency limit of passband ≈ bandwidth.

$$f_{max} < \frac{1}{4 t_r \eta \frac{L}{2\pi R} \frac{\Delta p}{p}}$$

for

$\frac{L}{2\pi R} = 0.25$ $\quad t_r = 4\mu s$ (rev. time), $\Delta p/p = 5 \times 10^{-3}$, $\eta = \left| \frac{1}{\gamma_t^2} - \frac{1}{\gamma^2} \right| \approx 1$

This gives $f_{max} < 50$ MHz.

The obvious cures for this are to place the pick-up and kickers close together, and limit the bandwidth for the low momentum cooling systems, with the possibility to extend the bandwidth as the momentum cooling progresses.

3. The filter method for momentum cooling requires that the Schottky bands used are clearly separated, this also limits the available an bandwidth to :

$$f_{max} < \frac{1}{t_r \eta \frac{\Delta p}{p}}$$

It may be possible to use techniques based on time of flight measurements, between pick-up and kicker to extend cooling to higher frequencies.

4. The long delays involved for slow particles mean that very long cables are required, e.g. for β = 0.05 about 500 meters of cable would be needed. The development of digital delays and notch filters would be very useful here.

If we take into account all the above constraints we arrive at the conclusion that three separate cooling systems will be needed, one for "high" momenta above 200 MeV/c, a second to cover the range 100 to 200 MeV/c, and a third for the ultra-low momenta below 100 MeV'c. These new systems are outlined in Table 2 and Figures 4 to 7. However the problems of bad miximg between the pick-up and kicker may still be apparent when using the "high momentum" cooling system at momenta below 300 MeV/c.

Finally one can estimate the ideal cooling time for the proposed 60 MeV/c longitudinal cooling, shown in figure 6. If the bandwidth is limited to 50 MHz, one obtains, with an initial dp/p of $\pm$ 2.5 10^{-3}, a cooling time of about 400 seconds for 10^9 particles.

REFERENCES

1. N. Tokuda, Traveling Wave Pick-ups and Kickers for Stochastic Cooling at Low Beam Velocity, these Proceedings.

Table 2 : Future systems

SYSTEM	MOMENTUM RANGE (MeV/c)	PICK-UP TYPE	SIGNAL ADDITION	AMPLIFIER	FREQUENCY BAND (MHz)
H1	200-2000	LOOP-COUPLER	COMBINER	ROOM TEMP	50-500
V1	200-2000	LOOP-COUPLER	COMBINER	ROOM TEMP	50-500
M1	450-2000	CAP FERRITE	COMBINER	ROOM TEMP	20-300
H2	100-200	LOOP-COUPLER	TRAVELING WAVE	CRYOGENIC	20-300
V2	100-200	LOOP-COUPLER	TRAVELING WAVE	CRYOGENIC	20-300
M2	100-609	GAP FERRITE	COMBINER	ROOM TEMP	20-200
H3	60 (20)	MEANDER LINE	TRAVELING WAVE	CRYOGENIC	10-150
V3	60 (20)	MEANDER LINE	TRAVELING WAVE	CRYOGENIC	10-150
M3	60 (20)	HELIX LINE	TRAVELING WAVE	CRYOGENIC	5-50

Figure 4 : High momentum
(200-2000 MeV/c)

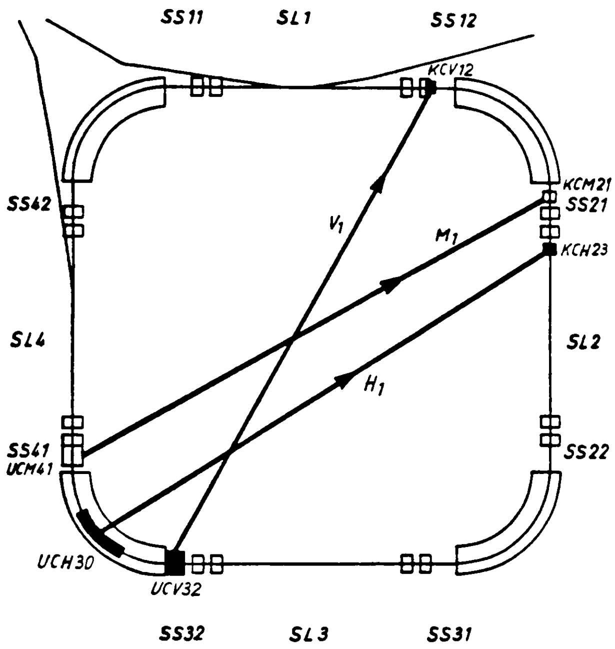


Figure 5 : Low momentum
(100-200 MeV/c)

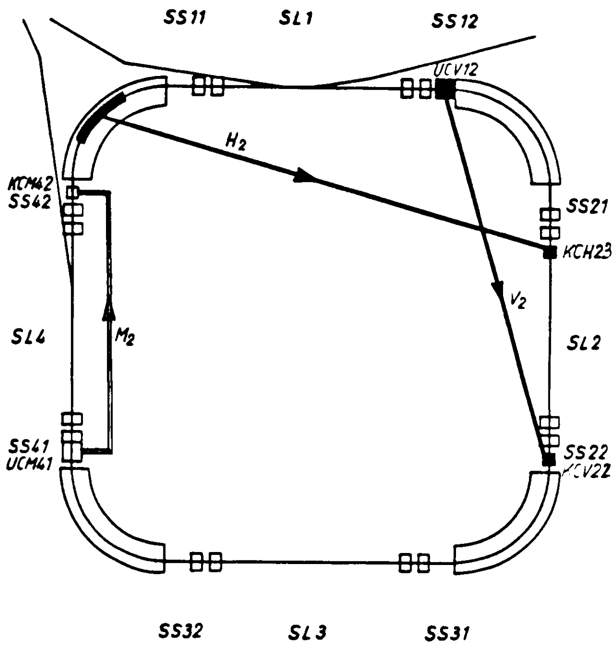


Figure 6 : Ultra low momentum
(60 MeV/c)

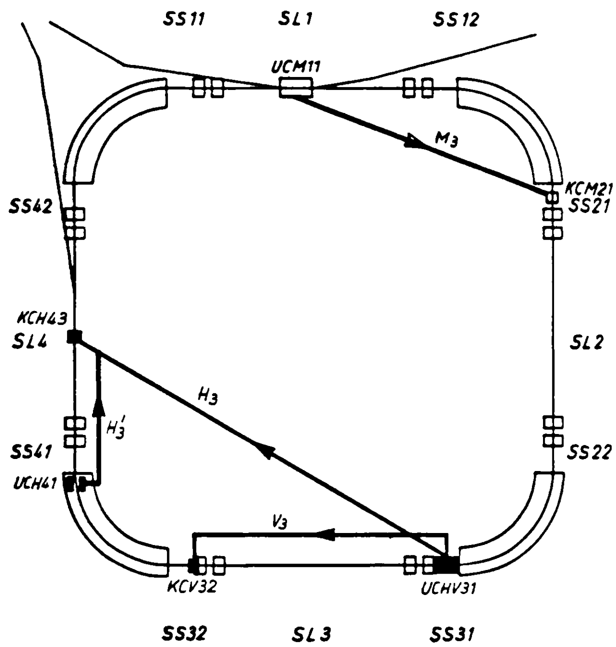


Figure 7 : All Systems