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High-Energy Electron Cooling at LEAR.

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Summary. — The possibility of using electron cooling in the LEAR ring, operating as a p-$\bar{p}$ collider between 0.6 and 2.0 GeV/c, is investigated. Cooling times at different energies and expected luminosities are evaluated. The project of an electron source ((100 ÷ 700) keV, 10 A d.c., $j = 5 \cdot 10^3$ A/m^2) with high-efficiency energy recovery is proposed. Problems regarding cathode, optics, beam qualities and diagnostic methods are tackled.

PACS. 29.15. – Electrostatic, collective and linear particle accelerators.

1. – Introduction.

The electron cooling method was conceived by BUDKER (¹) in 1966 for effectively damping betatron and synchrotron oscillations of ion beams in a

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(¹) G. Y. BUDKER: *At. Energy*, 22, 346 (1967).

storage ring. It is based on repeated interactions of heavy particles, like (anti)-protons circulating in a storage ring, with a dense and cold electron beam. The electron beam is admitted in one straight section of the storage ring where electrons travel along a few metres together with (anti)protons and absorb (anti)proton oscillation energy by Coulomb interactions. The electron beam is constantly renewed and the (anti)proton beam will be cooled down to a temperature $T_{p,\bar{p}}$, which is ideally equal to the electron temperature T_e:

$$T_{p,\bar{p}} \simeq T_e \to \theta_{p,\bar{p}} \simeq \left(\frac{m_e}{M_{p,\bar{p}}}\right)^{\frac{1}{2}} \theta_e \,,$$

where $\theta_{p,\bar{p}}$ and θ_e are the angular divergences of the (anti)proton and electron beam, respectively.

Because of the small ratio $m_e/M_{p,\bar{p}}$, the thermalization is extraordinarily favourable for the (anti)proton beam. The time constants for reducing the velocity spread of the (anti)proton beam may be deduced from the plasma theory (2).

The electron cooling method was experimentally confirmed at Novosibirsk in 1974 (3) and in an experiment performed at CERN during 1979 in the ICE storage ring (4).

In this paper we propose an electron cooling device for LEAR operating as minicollider between 0.6 and 2.0 GeV/c for each beam, in order to improve the beam quality and to increase the luminosity.

The use of the electron cooling for increasing the luminosity has been envisaged some time ago for the SPS collider (5) and for LEAR (6); the latter proposal has been further developed (7).

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(2) L. SPITZER: *Physics of Fully Ionized Gases* (New York, N. Y., 1956).

(3) G. Y. BUDKER, N. S. DIKANSKY, V. I. KUDELAINEN, I. N. MESHKOV, V. V. PARKHOMCHUK, D. V. PESTRIKOV, A. N. SKRINSKY and B. N. SUKHINA: *Part. Accel.*, **7**, 197 (1976).

(4) M. BELL, J. CHANEY, S. CITOLIN, H. HERR, H. KOZIOL, F. KRIENEN, G. LEBÉE, P. MØLLER-PETERSEN, G. PETRUCCI, H. POTH, T. SHERWOOD, G. STEFANINI, C. TAYLOR, L. TECCHIO, C. RUBBIA, S. VAN DER MEER and T. WIKBERG: *Phys. Lett. B*, **87**, 275 (1979); M. BELL, J. CHANEY, H. HERR, F. KRIENEN, P. MØLLER-PETERSEN and G. PETRUCCI: *Nucl. Instrum. Methods*, **190**, 237 (1981).

(5) C. RUBBIA: *Relativistic electron cooling for high-luminosity* p$\bar{\text{p}}$ *colliding beams at very high energies*, contributed paper to the *Joint LBL-Fermilab Workshop for High Luminosity High Energy* p$\bar{\text{p}}$ *Colliding Beams, Berkeley, March 2-31, 1978.*

(6) P. DALPIAZ: *Proceedings of the Joint CERN-KfK Workshop on Physics with Cooled Low Energetic Antiprotons, March 19-21, 1979*, edited by H. POTH (1979), p. 111.

(7) U. BIZZARRI, M. CONTE and L. TECCHIO: *Proceedings of the V European Symposium on Nucleon-Antinucleon Interactions, Bressanone, Italy, June 23-28, 1980*, edited by Istituto Nazionale di Fisica Nucleare, p. 19; U. BIZZARRI, M. CONTE, L. TECCHIO and A. VIGNATI: *Project of a high energy electron cooling at* LEAR, Report CNEN 81.5,

A short description of the electron cooling theory is first given and the cooling times at different energies are then estimated.

In the next part of this paper the advantages of using electron cooling in LEAR collider are discussed, by evaluating also its effect on the (anti)proton beam. In the last part the whole apparatus is presented. Besides, an electron beam with appropriate characteristics has great interest in the field of « free-electron laser » (FEL) (8), for microwave production in the submillimetre range, these microwaves being of great interest in plasma diagnostic and, perhaps, heating.

2.

2'1. *Electron cooling.* – The problem of a proton-electron gas was theoretically treated by SPITZER (2). The analogy with the electron cooling mechanism permits to adopt the same physical approach. In order to estimate the damping rate, the force acting on the (anti)proton has to be considered; the drag force is calculated from the momentum transferred in all possible electron-(anti)-proton collisions.

In the (anti)proton rest system, the interaction is described by classical Rutherford scattering and the amounts of momentum transferred are limited by head-on collisions and by the Debye shielding distance. These considerations give for the drag force (9)

$$F = -\frac{4\pi e^4 Ln}{m_e}\int \mathrm{d}^3 V_e \, \frac{\boldsymbol{V}_p - \boldsymbol{V}_e}{|\boldsymbol{V}_p - \boldsymbol{V}_e|} f(V_e)\,,$$

where $L \simeq 20$ is a logarithmic factor depending on the cut-off, n is the electron density, $f(V_e)$ the electron distribution in velocity space, m_e the electron mass, V_e and V_p are the electron and the (anti)proton velocities, respectively. For a flattened electron distribution (6,10) and in the absence of axial magnetic

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Frascati (1981); U. BIZZARRI, M. CONTE, R. SCRIMAGLIO, L. TECCHIO and A. VIGNATI: *Electron cooling device at* 500 keV *with a Cockcroft-Walton generator*, Report INFN, Frascati (1981).

(8) L. R. ELIAS: *Electrostatic accelerator free electron laser*, Quantum Institute University of California, Santa Barbara, QIEFEL 004/80.

(9) A. H. SORENSEN: *Calculations on electron cooling*, CERN p̄ LEAR Note 07.

(10) G. Y. BUDKER, YA. S. DERBENEV, N. S. DIKANSKY, I. N. MESHKOV, V. V. PARKHOMCHUK, D. V. PESTRIKOV, R. A. SALIMOV, A. N. SKRINSKY and B. N. SUKHINA: *Study on electron cooling of heavy particle beams made by the VAPP-NAP Group at the Nuclear Physics Institute of the Siberian branch of the USSR Academy of Science at Novosibirsk*, Yellow Report CERN 77-08.

field, the cooling time in laboratory frame is

$$\tau = \frac{4}{\pi\sqrt{2\pi}}\frac{e}{j_e r_p r_e \eta L}\begin{cases} \beta^4\gamma^5\theta^3_{p,\bar{p}} & (\theta_{p,\bar{p}} > \theta_e)\,, \\ \beta\gamma^2\left(\dfrac{T_e}{m_e c^2}\right)^{\frac{3}{2}} & (\theta_{p,\bar{p}} < \theta_e)\,, \end{cases}$$

where $\theta_{p,\bar{p}}$ and θ_e are, respectively, the (anti)proton and electron divergences, T_e the electron temperature, r_p and r_e the classical radii of the proton and electron, j_e the electron current density in the laboratory system and η the fraction of the circumference of the storage ring occupied by the electron beam. It is immediately apparent from this formula that, if the beam is initially very cold, it is easy to keep it cooled. The theory of electron cooling contains many fine details concerning the influence of the strong anisotropy of the electron velocity distribution in the centre of mass, the influence of the magnetic field on the Coulomb interactions, the contribution of small and large impact parameters, and the relative velocities of the (anti)protons with respect to the electrons.

All these effects are widely discussed in many papers by different authors ([11]). In any case the above equation is sufficiently correct for a good evaluation of the cooling time.

2'2. *Cooling time evaluation.* – For our calculation we consider an electron beam of 10 A current, 5 cm diameter, 0.5 eV of temperature and a cooling region of 1.5 m length. If p and p̄ beams are injected in the multiturn mode, a sequence of batches of small emittance will appear, till the designed total number of p (p̄) will be obtained. Whilst ring filling is taking place, electron cooling is being set up.

By assuming a $100\pi \times 12\pi$ (mm·mrad)^2 emittance at injection, where other parameter of interest (see table II) are 600 MeV/c p, p̄ momenta $\beta_H = \beta_V \simeq 5$ m and $\Delta p/p \simeq 3\cdot 10^{-3}$, $\theta_e < \theta_{p,\bar{p}} = 5$ mrad, the cooling time is given by

$$\tau = \frac{4}{\pi\sqrt{2\pi}}\frac{e\beta^4\gamma^5}{r_e r_p \eta j_e L}\theta^3_{p,\bar{p}} = 78\ \text{s}\,,$$

where $j_e = 5\cdot 10^{-3}$ A/mm^2, $\eta = 0.002$ and $L = 20$. After this precooling operation, both p, p̄ beams can be accelerated at the working energy, practically without changing their temperature. In order to compensate beam broadening, due mainly to beam-beam interaction, electron cooling must be kept on work.

([11]) A. H. SORENSEN: *Influence of a strong longitudinal magnetic field on electron cooling*, Institute of Physics, University of Aarhus, Denmark; YA. S. DERBENEV and A. N. SKRINSKY: *Part. Accel.*, **8**, 1, 235 (1978); M. BELL: *Part. Accel.*, **10**, 101 (1980); J. S. BELL and M. BELL: *Part. Accel.*, **11**, 233 (1981).

In these conditions ($\theta_{\mathrm{p},\bar{\mathrm{p}}} < \theta_{\mathrm{e}}$) the formula

$$\tau = \frac{4}{\pi\sqrt{2\pi}}\,\frac{e\beta\gamma^2}{r_{\mathrm{e}}r_{\mathrm{p}}\eta j_{\mathrm{e}}L}\left(\frac{T_{\mathrm{e}}}{m_{\mathrm{e}}c^2}\right)^{\frac{3}{2}} = 2.8\beta\gamma^2$$

can be used. Cooling times, estimated at different p, $\bar{\mathrm{p}}$ momenta, are gathered in table I. However, this theory is far from exact, and the magnetic field should improve all the expected times.

TABLE I.

$p_{\mathrm{p},\bar{\mathrm{p}}}$ (GeV/c)	β	γ	E_{e} (MeV)	τ(s)
0.8	0.649	1.31	0.158	9.9
1	0.729	1.46	0.235	14.4
1.5	0.848	1.88	0.453	26.8
2	0.905	2.355	0.692	44.7

3.

3·1. *Colliding beams.* – A low-energy p$\bar{\mathrm{p}}$ colliding-beam facility was proposed (some time ago) (12). The option was presented in the « Design study of a facility for experiments with low-energy antiprotons » (13), where LEAR is conceived as a minicollider. We discuss now the possibility to operate LEAR as a p-$\bar{\mathrm{p}}$ collider between 0.6 and 2.0 GeV/c. We calculate an upper limit for luminosities at different energies, assuming head-on collisions between proton and antiproton bunches of $6\cdot10^{11}$ particles each, and taking into account the Amman-Ritson limit (13). The optimum luminosity is given by

$$L = \frac{N_{\mathrm{p}\bar{\mathrm{p}}}f_{\mathrm{rev}}\Delta\nu\gamma}{(1+\beta^{-2})r_{\mathrm{p}}\beta_{\mathrm{V}}}\,,$$

where $\Delta\nu = 5\cdot10^{-3}$ in the absence of cooling and $\beta_{\mathrm{V}} = 5$ m is the value of the focusing function in the interaction region. The LEAR colliding-beam main parameters are listed in table II (13). The estimated upper limits for luminosities

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(12) P. DALPIAZ: *Electromagnetic annihilation in low energy* p-$\bar{\mathrm{p}}$ *colliding beams*, CERN p$\bar{\mathrm{p}}$ Note 06 (1st May 1977); P. DALPIAZ, L. TECCHIO and M. SCHNEEGANS: *Proceedings of the IV European Antiproton Symposium, Barr, Barre, France*, edited by A. FRIDMAN, CNRS, Vol. II (1979), p. 689; P. DALPIAZ: *Proceedings of the Joint CERN-KfK Workshop on Physics with Cooled Low Energetic Antiprotons, Karlsruhe, March 19-21, 1979*, edited by H. POTH (1979), p. 111.

(13) W. HARDT, L. HOFFMAN, P. LEFÈVRE, D. MÖHL, G. PLASS and D. SIMON: *Conceptual study of a facility for low energy antiproton experiments*, CERN/PS/DL/Note 79-1; *Design study of a facility for experiments with low energy antiproton* (LEAR), edited by G. PLASS, CERN PS/DL 80-7.

TABLE II. – *Colliding-beam properties.*

1) Lattice parameters ($Q_H = 2.3$, $Q_V = 2.7$)	
lattice functions (average) in the interaction region $\beta_H = \beta_V$ (m)	5
momentum compaction function α_p (m)	3.9
transition energy γ_t^2	-14^2

2) Beam parameters and luminosity	
momentum (GeV/c)	2
number of particles ($N_{\bar{p}} = N_p$)	$6\cdot 10^{11}$
beam size (2 r.m.s.) horizontal × vertical (mm²)	29·10
corresponding emittances $E_H \times E_V$ (mm·mrad)^2	$170\pi \times 20\pi$
bunched-beam momentum spread $\pm \Delta p/p$	$1\cdot 10^{-3}$
bunch length, total (m)	5
luminosity limit (cm^{-2} s^{-1})	$1.4\cdot 10^{29}$

3) Auxiliary quantities	
r.f. voltage/turn (kV)	55
frequency, $h = 1$ (MHz)	3.45
off-energy function $1/\gamma_t^2 - 1/\gamma^2$	-0.18
beam-beam tune shift $\Delta\nu$	$5\cdot 10^{-3}$
Laslett space charge tune shift ΔQ at 2 GeV/c	0.01
tolerable impedance at n-th revolution harmonic Z_n/n (Ω)	60
Growth time of Δp and bunch length due to intrabeam scattering (h) (without cooling)	0.6

TABLE III.

$P_{p,\bar{p}}$ (GeV/c)	f_{rev} (MHz)	β	γ	L (cm^{-2} s^{-1})
0.6	2.055	0.538	1.2	$2.2\cdot 10^{28}$
1	2.78	0.729	1.46	$5.5\cdot 10^{28}$
1.5	3.24	0.848	1.88	$1.0\cdot 10^{29}$
2	3.46	0.905	2.355	$1.4\cdot 10^{29}$

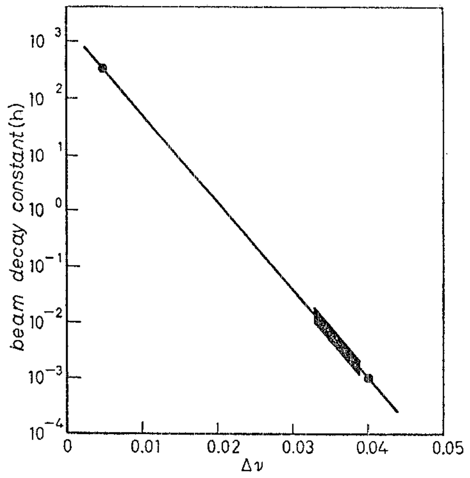

Fig. 1. – Plot giving the beam decay constant *vs.* the beam-beam tune shift.

are summarized in table III. From the plot giving the beam decay constant (fig. 1) *vs.* the beam-beam tune shift (^14^) and from the cooling times shown in table I, we can deduce the corresponding tune shift, tolerable in the presence of the proposed electron cooling method by assuming that the cooling time just compensates the beam decay constant. We can see that at 2 GeV/c an average $\Delta\nu \simeq 0.035$ is allowed, and this corresponds to an increase by a factor 7 of the luminosity compared with the example without cooling, where $\Delta\nu = 5\cdot10^{-3}$. In table IV these luminosities are summarized at different energies.

TABLE IV.

$P_{p,\bar{p}}$ (GeV/c)	L (cm^{-2} s^{-1})
0.6	$1.54\cdot10^{29}$
1	$3.8\cdot10^{29}$
1.5	$7.0\cdot10^{29}$
2	$9.8\cdot10^{29}$

A luminosity of the order of 10^{30} cm^{-2} s^{-1} is reached around 2 GeV/c for each beam. Application of the electron cooling method in order to reduce the beam bunch length is under study. In fact, the r.f. voltage needed to contain a bunch length l_b and a given $\Delta p/p$ may be written as (^13^)

$$U = \frac{\pi}{2}|\eta|\beta^2\gamma\left(\frac{\Delta p}{p}\right)^2 h_{r.f.}\left(\frac{1}{y(l_b)}\right)^2 0.938\ \text{MV}\,.$$

(^14^) B. ZOTTER: *Proceedings of the X International Conference on High Energy Accelerators, Protvino, July 23-29, 1977.*

As $y(l_b) \simeq 1.6 l_b/2\pi R = 0.1$ for $l_b = 5$ m, $|\eta| = 0.18$ at 2 GeV/c, $\Delta p/p = 10^{-3}$ is the momentum spread of the bunched beam and, assuming a first-harmonic r.f. system ($h_{\text{r.f.}} = 1$), one finds

$$U = 54\ \text{kV}\,.$$

By reducing $\Delta p/p$ through electron cooling, a shorter bunch length can be obtained mantaining the same r.f. voltage ([13,15,16]).

3'2. e-p, $\bar{\text{p}}$ *tune shift.* – The p, $\bar{\text{p}}$ tune shift due to co-rotating electrons in the cooling region is determined by the intensity and the size of the electron beam ([5])

$$\Delta\nu_{\text{p},\bar{\text{p}}} = \frac{j_e l R r_p}{2Q_V e c \beta^3 \gamma^3} = \frac{5.53\cdot 10^{-4}}{\beta^3\gamma^3}\,,$$

where $j_e = 5\cdot 10^{-3}$ A/mm² is the electron beam density, $l = 1.5$ m is the cooling region length, $R = 12.5$ m is the radius of LEAR and $Q_V = 2.7$.

As shown in table V, the p, $\bar{\text{p}}$ tune shift induced by the electron beam at different energies is negligible compared with the p-$\bar{\text{p}}$ tune shift discussed in the previous section.

TABLE V.

$P_{\text{p},\bar{\text{p}}}$ (GeV/c)	$\Delta\nu_{\text{p},\bar{\text{p}}}$
0.6	$2\cdot 10^{-3}$
1.0	$4.5\cdot 10^{-4}$
1.5	$1.36\cdot 10^{-4}$
2.0	$5.7\cdot 10^{-5}$

3'3. *Laslett tune shift.* – The Laslett space charge tune shift of each p and/or $\bar{\text{p}}$ beam imposes a limitation in beam intensities and depends on the main parameters of the machine and on the beam cross-section, and its evaluation for p, $\bar{\text{p}}$ cooled beams is essential. For a quick estimation, the Laslett tune shift may be writtén as ([17])

$$\Delta Q = \frac{N_{\text{p},\bar{\text{p}}} r_p R}{2\pi\beta^2\gamma\sigma^2 Q_V}\left(\frac{1}{\gamma^2} - f\right) = \frac{0.1}{\beta^2\gamma^3}\,,$$

where σ is the radius of the (anti)proton cooled beam inferred from the p-$\bar{\text{p}}$ $\Delta\nu$ at a given energy, $Q_V = 2.7$ and the ion neutralization f is set equal to zero. The resulting ΔQ for unbunched beams at different energies is given in table VI.

([15]) H. HERR and D. MÖHL: *Relativistic electron cooling in* ICE, PD/DL/Note 78-4.

([16]) M. CONTE: *Head-on collisions in* LEAR, CERN $\bar{\text{p}}$ LEAR Note 46.

([17]) E. KEIL: *Intersecting storage rings,* CERN 72-14.

TABLE VI.

$P_{\bar{p},p}$ (GeV/c)	ΔQ
0.6	0.2
1.0	0.06
1.5	0.02
2.0	$9.3\cdot 10^{-3}$

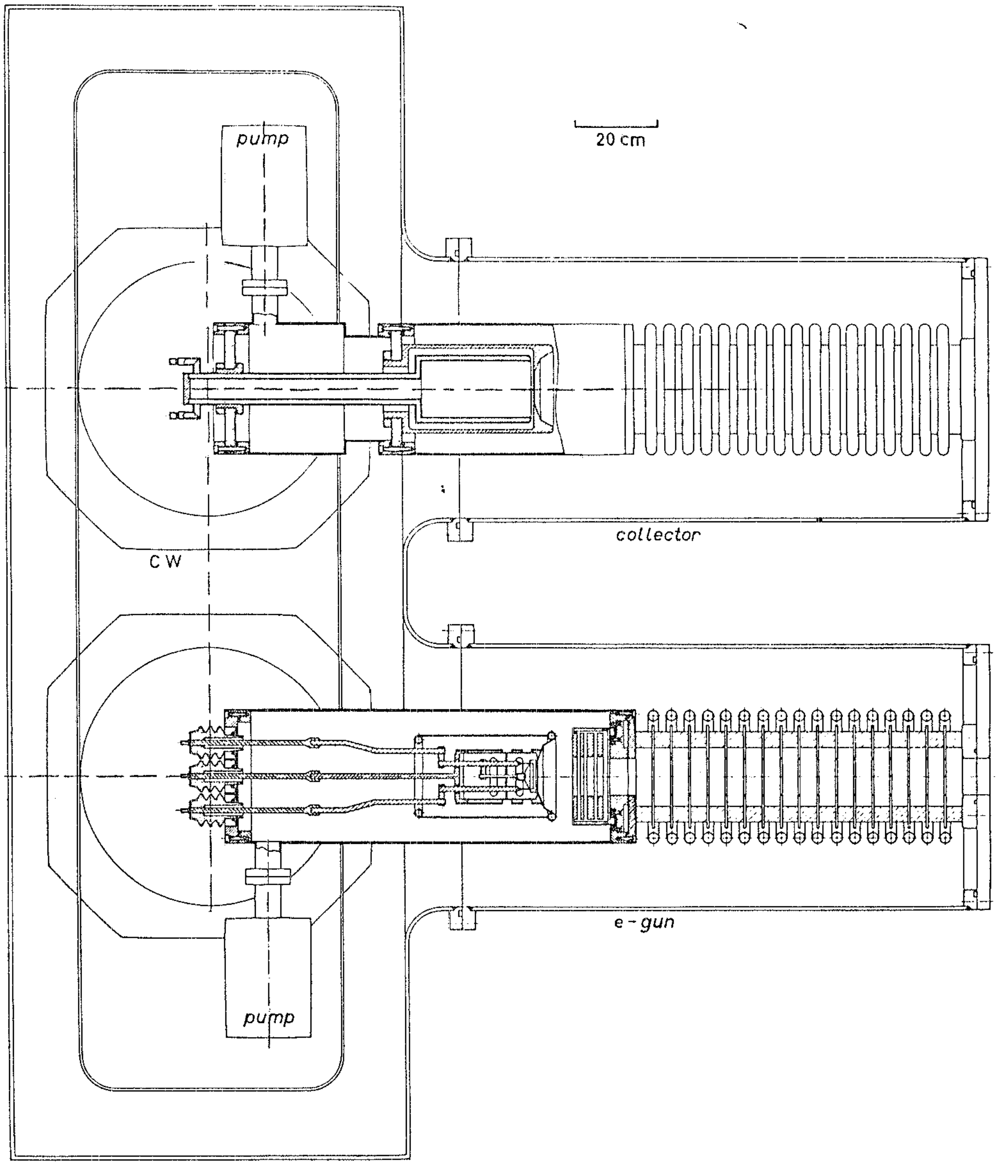

Fig. 2. – The proposed scheme for the electron gun and the energy recovery system.

4. – Electron cooling device.

In order to achieve (anti)proton cooling, as discussed before, we think of setting up the electron device in the straight section *SL*3 of LEAR ([13]). The device is conceived for cooling both proton and antiproton beams.

The main parts of the electron cooling apparatus are:

a) high-voltage generator,

b) electron gun and accelerating tube,

c) drift region,

d) decelerating tube and collector.

Due to insulation reasons all these parts are contained in a stainless-steel oil tank properly shaped. In fact, the electron beam, from cathode to collector, must be immersed in an axial magnetic field; thus two solenoids, connected to the drift region by bending toroids, must be located close to the electron gun, as shown in fig. 2. Oil insulation has been preferred to gas insulation, in order to avoid an high-pressure tank and to guarantee a good power dissipation.

The availability of such a kind of apparatus depends very much on the possibility of having a very efficient recovery of the electron energy, in order to avoid an electron dump of the order of a few MW, and to save installed power.

The whole apparatus will have to match its vacuum with the severe LEAR vacuum condition ($< 10^{-10}$ Torr).

4.1. *High-voltage generator.* – Circulating (anti)protons of 2.0 GeV/c require electrons with about 700 keV kinetic energy; other requirements, seen previously, imply a very cold electron beam ($\sim 10^{-6}$ m·rad emittance and $\Delta p/p < < 10^{-3}$) of 10 A in current and 5 cm in diameter.

Among several types of high-voltage generators, we have chosen the Cockcroft-Walton one, as it can be built in different stages with relative ease.

A symmetrical cascade Cockcroft-Walton generator is now under construction. It consists of 14 stages, 50 kV each, driven by a 15 kHz-20 kV oscillator of 2 kW power.

The residual ripple is evaluated to be of the order of 10^{-4}.

As cooling times are of the order of seconds or longer, this fast modulation of the electron energy should not affect the proton energy. A current of 2 mA is supposed to be sufficient for compensating the current lost along the whole electron path and for supplying the voltage dividers, which are required in order to stabilize voltage and to activate the electrodes of both accelerating and decelerating tubes.

In fact, in agreement with former achievements ([10]), the fractional current loss is of the order of 10^{-4}, which corresponds in our example to 1 mA, compared with 10 A of the regenerated beam. The high-voltage terminal must be equipped with the appropriate power supply for heating the cathode (200 W), polarizing the focusing electrodes ($3 \times (20 \div 50)$ kV, 200 W) and activating the depressed collector (1 kV, $(10 \div 15)$ kW). Besides, two ion pumps have to be foreseen for securing the due high vacuum within both tubes.

Hence we can draw that we need a total power of 20 kW at 700 kV. This power will be transferred from the mains to the « hot » terminal by means of a cascade of three insulating transformers. Moreover, remote control systems must be set down for regulating the cathode power and tuning the beam. Finally, an efficient heat dissipation from the high-voltage terminal must be achieved by means of a flux of oil through insulated pipes.

4'2. *Electron gun and accelerating tube.* – The kind of gun we intend to adopt will be possibly similar to the ones already successfully used (18).

The electron gun uses a reserve cathode indirectly heated at 1050 °C, with a diameter of 5 cm. As the electron beam must have a rest frame temperature less than 1 eV (*i.e.* 11 604.5 K), the first electrodes have to be designed with a classical Pierce geometry, followed by standard « resonant optics », in order to minimize the electron spiral. All the system from the cathode to the collector is immersed in the axial magnetic field. This gun brings the electrons to 50 keV, the further acceleration up to 700 keV being accomplished by an additional accelerating tube. This tube consists of a column of 20 ceramic rings, spaced by thin (3 mm) stainless-steel annular electrodes, which are polarized through a resistive voltage divider made of a spiral of resistances wrapped around the tube and protected by guard rings. The total length of the accelerating tube is about 1 m and the highest electric stress experienced by each ceramic ring is 15 kV/cm. Also at the end of the accelerating tube a diverging lens effect exists, which has to be compensated either by an appropriate graduation of the electric field or by setting down an additional resonant section (see fig. 2).

4'3. *Drift region.* – After having left the gun, the electron beam is bent to be superposed with the (anti)proton beam. The bending is accomplished by means of a toroidal field.

The cooling occurs in 1.5 m long drift region, where a uniform-field solenoid confines the electron beam. Compensating dipoles perform the due corrections.

4'4. *Decelerating tube and collector.* – This tube has the same optics of the accelerating column. In fact, the couple of radial-velocity compensators is still necessary for reducing radial components, as any energy coupled to gyration

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(18) M. Bell, J. E. Chaney, F. Krienen and P. Møller-Petersen: *Report on the CERN electron cooler*, CERN $\bar{p}$ LEAR Note 29; *Design Report, Fermilab electron cooling experiment* (November, 1977).

is difficult to recover into longitudinal motion. Thus, if the deceleration process is looked after with particular care from top energy down to 30 keV, the further energy decrease can take place according to existing successful methods ([6,7]). Evaluations have been made which show that the electron beam characteristics, like transversal emittances and momentum spread, are not much spoiled by the process of removing « thermal » energy from (anti)proton beams. As gun and collector are electrically connected to the same h.v. generator, all the spreads due to uncompensated fast ripples and to the slow drift of the tension can be disregarded. Hence the sole energy spread effect which has to be considered is the one related to the electron thermal motion inside the cathode. As this spread has a fractional value less than 10^{-4}, we consider it sufficient to use a single-plate collector operating at about 1 kV, expecting thus an energy dissipation bounded around 10 kW. One difficulty in maximizing the collection efficiency is given by the secondary emission from the collector surface. A way of avoiding this difficulty is to employ materials with low secondary-emission coefficient, like titanium and platinum. Another way consists in impeding the back-acceleration of secondary electrons. Also in the collector it is necessary to provide an efficient heat dissipation system. This is shown in fig. 2.

5. – Diagnostics.

Beam position and electron temperatures are very important information to be picked up. As in the first stage of our work no electron-proton beam matching is foreseen, methods based upon cooling and correlated phenomena cannot at the moment be considered. Therefore, we must envisage other methods. A first low-current diagnostic, not necessitating energy recovery, can be used for testing optics tuning, alignments and magnetic-field uniformity ([10]).

In order to perform tests at full intensity, nondestructive methods have to be taken into account. We think of using the proposed measurement ([5]) of the r.f. spectrum emitted by electrons spiralling around field lines as a measure of the transverse temperature of the beam.

As far as beam positioning is concerned, we intend to employ perturbative methods, as, for instance, impulsive deflecting fields in connection with split induction electrodes.

Beam profile could be continuously tested by slight penetration of thin needles, controlled by feed-back.

6. – Final remarks.

Many of the open problems, mentioned in this work, can be solved only by experimental tests. For that reason, we intend to speed up the construction of a prototype, which is being built in the Frascati Laboratories. We plan to start the first tests at the beginning of 1982.

This device will, however, be employed as a free-electron laser for the production of millimetre and/or submillimetre microwaves, used in plasma physics either for diagnostic or for heating.

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● RIASSUNTO

Si valuta la possibilità di usare il raffreddamento ad elettroni nell'anello di accumulazione LEAR, operante come « p-$\bar{p}$ collider » tra 0.6 e 2.0 GeV/c. Sono valutati i tempi di raffreddamento a differenti energie e le luminosità previste. Si propone il progetto di una sorgente di elettroni ((100 ÷ 700) keV, 10 A d.c., $j = 5 \cdot 10^3$ A/m^2) con recupero di energia ad alta efficienza. Si affrontano i problemi riguardanti il catodo, l'ottica, la qualità del fascio e i metodi diagnostici.

Электронное охлаждение при высоких энергиях в кольце LEAR.

Резюме (*). — Исследуется возможность использования электронного охлаждения в кольце LEAR, работающем в режиме p-$\bar{p}$ соударений с импульсами от 0.6 до 2.0 ГэВ/с. Оцениваются времена охлаждения при различных энергиях и ожидаемые светимости. Предлагается проект электронного источника ((100 ÷ 700) кэВ, 10 А, $j = 5 \cdot 10^3$ А/м^2) с высокой эффективностью регенерации энергии. Рассматриваются проблемы, касающиеся катода, оптики, качества пучка, и методов диагностики.

(*) *Переведено редакцией.*