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TITOLO PHYLOSOPHY AND COST OF THE INJECTION SYSTEM FOR CARST.-	NOME S. Tazzari	

1. General specifications and remarks

The general specifications for any synchrotron light source injection system are :

- full Main ring (MR) energy . For the Trieste machine (CARST) this means that the injector should be able to provide a beam energy of up to 2 GeV .
- MR filling time to maximum foreseen current , much shorter than the beam lifetime .

Both requirements point to more costly solutions than the " minimum configuration " ones that would still work . However the larger initial investment is in our opinion more than repaid by the savings afforded during operation through shorter commissioning time, faster start-up after a vacuum breakdown, and high overall operating efficiency .

Full energy injection guarantees that the problems to arise , in connection with the need for keeping a large number of beam lines independently aligned to very high precision, will be reduced to a minimum. Also , lifetime under poor vacuum start-up conditions can be much shorter than its design value for the steady state regime . A high energy, high current injector can reduce the time needed to achieve a good vacuum by large factors,thereby improving the MR overall reliability. At start-up injection times should ideally be of the order of a minute; in the steady state they can be compared to the asymptotic lifetime (in our case ≈ 6 h) and be correspondingly longer.

The injected beam emittance and energy spread are of paramount importance when considering very low emittance storage rings . This because , on one hand strong focusing and good field quality are required so that it is advantageous for both cost and reliability considerations to keep the MR physical chamber aperture to a minimum (compatible with the other constraints) and , on the other, the MR space and momentum acceptances can be limited by nonlinear dynamics effects to below what afforded by the chamber physical size.

Finally , the potential for (cost-effectively) upgrading the injector energy in view of possible unforeseen developments is a definite advantage.

2. Electrons versus positrons

The next important issue is whether one should operate the MR on electrons or positrons.

Several existing SR sources, having beam emittances much larger than those expected from the 'third generation' rings such as CARST, are proven to operate more reliably and efficiently with positrons than with electrons. This because electron beams tend to trap the positive ions they create in the residual gas ; the trapped ion cloud can then produce instabilities that result in sudden lifetime changes and/or beam blowup.

Experimental results on ion trapping are scarce and in qualitative agreement only with theoretical predictions .

Thus , although the theory predicts ion trapping to become more difficult when the beam emittance is decreased , enough uncertainty exists to justify designing for an injector with e^+ injection capability (at lest as an option).

However, for any injector system in the energy range we are considering the ratio of electron to positron production is large (electron current is usually limited only by the acceptable energy spread and, possibly, by instabilities). This means that it is much easier to satisfy start-up filling time requirements (see §1.) with electrons .
e^- injection should therefore be available for use under start-up conditions and be designed to achieve filling times of the order of one minute ; positron filling times will then automatically fall in the range of a few (tens of) minutes , still compatible with the requirement of being much shorter than the steady state lifetime of $\approx$ 360 minutes.

From the point of view of cost the e^+ versus e^- issue is extremely important : an adequate "e^- only" injector is intrinsically cheaper than a system having positron capability .
As a consequence , cost-conscious designers tend to design injection systems that can be built in stages : a lower cost "e^- only" first stage to which a second , e^+ , stage can be added if and when required .

3.Linac plus Booster synchrotron

An injection system consisting of a Linac plus a 10 Hz Booster synchrotron (L+B) has been proposed by the LNF group [1].

Its main parameters are listed in Table 1.
Several possible versions of the e+/e- Linac are presented according to reference (2). More work needs to be done to arrive to the final optimization . However, the solutions that have been studied allow the cost bracket , as presented in Table 2., to be estimated . An insight into the cost versus performance tradeoffs can also be gained.

The proposed system matches the general requirements outlined in the previous paragraphs extremely well :

- It provides the right filling times , at top energy , for both electrons and positrons with comfortable safety margins.
- It provides very good beam quality by letting the beam damp in the booster .
- It can be built in stages , the first stage (e- only) costing about one half of the total.
- When properly designed , it can be upgraded to about 3 GeV at a much less than linearly increasing cost.

4. Comparison with the 1.8 GeV (three times recirculated) LINAC (RLIN)

The cost of the basic .6 GeV Linac was estimated [3] to be 25 MSFr. To this the cost of two recirculation channels has to be added , for which my own estimate is 7. MSFr. The overall cost estimate therefore comes to 32 MSFr.
Injection rates of the same order as the L+B ones have been presented [3].

By going through the same arguments as for the previous solution one finds:

- Beam quality , at least for e+, is worse than for the (L+B) by a factor of ≈10 both in emittance and in $\Delta p/p$. The effects of this on the MR design have to be assessed.
- Safety factors are much reduced. In particular the feasibility of the proposed recirculation with the quoted beam parameters has to be demonstrated.

- "e$^-$ only" operation would reduce the cost by less than one third.
- The cost of energy upgrading (provided the recirculation lines have been properly designed) would scale next to linearly with energy.

REFERENCES

(1) P.Patteri : Adone Int Memo's G-72, G-81
P.Patteri, F.Tazzioli : Adone Int Memo's AF-5, AF-6
S.Kulinsky, b.Spataro, F.Tazzioli : Preliminary proposal for the Afrodite injector Linac.
CGR MeV : private communication.
G.Voss, Hemmie, Febel (DESY) : private communications.

(2) S.Kulinsky, b.Spataro, F.Tazzioli: Linac for Afrodite. Solutions with pulse compression. In publication.

(3) C.Pellegrini : private communication (presented to the Trieste SC Meeting in June)

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Table 1

Linacs :		1.C6R	3.LNF	6.LNF	7.LNF
LINAC Low En./High current					
SLED		NO	YES	YES	YES
# Modulators		35	35+10	35	20
#Sections		1+2	1+3	1+4	1+1
P_{in}/Section	MW	5/15	5/25	12.5/25	5/15
Section length	m	1.14.5	1.1/4.5	2/2.5	1.1/4.5
ΔE/Section	MeV	15/58	15/75	30/51	15/58
ΔE/unit length	MeV/m	13.6/12.9	13.6/17	15/20.4	13.6/13
(@ converter)					
E_{e^-} (unloaded)	MeV	130	240	234	73
E_{e^-} (full load)	MeV	91	200	182	70
$q^{(-)}$	nC	100	100	100	3
Δt	ns	10	10	10	10
i_p^- (peak)	A	10	10	10	.3
$\langle i \rangle^-$ @ 10 Hz	nA	1000	1000	1000	30
$\Delta p/p$ (full load)		.3	.17	.22	.02
η/E_{e^-}(conv. eff)	1/GeV	$2\ 10^{-2}$	$2\ 10^{-2}$	$2\ 10^{-2}$	_
LINAC : High en./Low current					
SLED		NO	YES	YES	_
# Modulators		2	1+1/2	1	_
KLY Peak Power	MW	35	35+10	35	_
#Sections		1+4	1+3	4+1	_
P_{in}/Section	MW	5/15	5/25	12.5/25	_
Section length	m	1.1/4.4	1.1/4.4	2/2.5	_
ΔE/Section	MeV	15/58	15/75	30/51	_
ΔE/unit length	MeV/m	13/14	17/14	15/20.4	_
E^-_{max}(unloaded;1+2)	**MeV**	375	480	468	_
$q^{(-)}$	nC	3.5	4.5	4.4	_
i_p^- (peak)	**mA**	350	450	440	_
$\varepsilon^{(-)}$	πmrad	$8\ 10^{-7}$	$7\ 10^{-7}$	$7\ 10^{-7}$	–
$\gamma\varepsilon^{(-)}$	πmrad	$6\ 10^{-4}$	$6\ 10^{-4}$	$6\ 10^{-4}$	–
E^+_{max}(unloaded)	**MeV**	245	240	234	_
$q^{(+)}$	nC	.18	.4	.37	_
i_p^+ (peak)	**mA**	18	40	37	_
$\varepsilon^{(+)}$	πmrad	10^{-5}	10^{-5}	10^{-5}	–
$\gamma\varepsilon^{(+)}$	πmrad	$6\ 10^{-3}$	$6\ 10^{-3}$	$6\ 10^{-3}$	–
$\Delta p/p$		± .01	± .01	± .01	–
frep	Hz	≥ 10	≥ 10	≥ 10	_
$\langle i \rangle^-$	nA	35	45	44	_
$\langle i \rangle^+$	nA	**1.8**	**4.**	**3.7**	_

TITOLO **Table 1 ct'd**

Linac out : c'td					
$N°^{(-)}/10^{10}$	e^-/s	22	28	28	30
$N°^{(+)}/10^{10}$	e^+/s	1.25	2.5	2.3	_
Lin./Boost. Transfer eff.		.3	.3	.3	.15
BOOSTER					
E_{MAX}	GeV	2			
B_{MAX}	T	1.2			
E_{inj}	GeV	$\geq .2$			.07
B_{inj}	G	≥ 1200			420
f_{rep}	Hz	10			
$2\pi R$	m	79			
τ_D	ms	8.8			
τ_{rev}	µs	26.5			
ε	πmrad	$9.5\ 10^{-8}$			
$\Delta p/p$		$5.8\ 10^{-4}$			
$1/f_0$	nC/A	264			
i_p^- (circulating)	mA	4	5	5	1.7
$\langle i \rangle^-$	nA	10.5	13.5	13.5	4.5
i_p^+ (circulating)	mA	.2	.45	.42	_
$\langle i \rangle^+$	nA	.55	1.2	1.1	_
Boost./Main ring Transf. eff.		.85	.85	.85	.85
MAIN RING					
E_{MAX}	GeV	2			
$\langle i \rangle^-$ (inj. @ 10 Hz)	nA	9			
$\langle i \rangle^+$ (inj. @ 10 Hz)	nA	.5			
$2\pi R$	m	270			
τ_D (@ E_{MAX})	ms	14			
$1/f_0$	nC/A	900			
T^-(time to inj.400 mA^-)	m	.67	.52	.52	1.6
T^+(time to inj.400 mA^+)	m	13	5.9	6.4	_

TABLE 2

INJECTION SYSTEM COST ESTIMATE

		MIN	MAX	⟨AV⟩
LINAC e^+/e^-	(G£it)	7.2	8.9	8.0
LINAC e^-	(G£it)	1.8	2.0	1.9
BOOSTER	(G£it)	4.8	6.9	5.9
Total e^+/e^-	(G£it)	**12.0**	**15.8**	**13.9**
	(MSFr)	**14.6**	**19.3**	**16.95**
Total e^-	(G£it)	**6.6**	**8.9**	**7.79**
	(MSFr)	**8.0**	**10.9**	**9.45**

Original estimate for e^+/e^- : (G£it) : 12.4
(CARST document) (MSFr) : 15.1

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