A Fast Injection System with a Superconducting Accumulator Ring for a Tau Charm Factory *

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I. Introduction

The type of high luminosity, storage ring collider being studied by SLAC for a tau-charm factory will require high energy, low emittance sources of positrons and electrons suitable for filling the rings. Ideally, the fill time should be much shorter than the luminosity life-time of the rings. For the purpose of estimating the characteristics of the injection system, the maximum fill time is taken to be $\mathcal{O}$ (100) seconds. The characteristics of the asymmetric storage rings have been studied by Jowett [1]. In his parameter studies, Jowett has found that the luminosity life time should be $\mathcal{O}(10^4$ sec). Similar studies conducted at SLAC prior to this workshop have resulted in a set of specifications to be met by the designers of the injection system.

In the design of the injection system, several choices are available:

a) Injection from a linac at the full energy of the rings or injection at lower energy into an intermediate booster synchrotron.

b) Generation of positrons with high energy electron beams via conventional techniques for secondary particle production or use of novel positron sources such as radio-isotope sources and Malmberg traps.

c) Use of a conventional damping/accumulator ring to cool the positron beam or use of a compact, superconducting ring such as one suitable as an X-ray lithography source.

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d) Accelerating electrons (and positrons) to high energy using conventional linac technology or using high gradient linacs plus GW power rf-sources being developed for linear colliders.

e) Generation of electron at moderate brightness using conventional rf-guns followed by an electron damping ring or using photo-cathode supplied ultra-high brightness guns such as those needed for TeV class linear colliders and free electron lasers operating at X-ray wavelengths.

II. Reference design of the injection system

The proposed tau-charm factory at SLAC is meant to be a relatively low risk project from the point of view of machine physics. Consequently, the workshop was given the charge of using only well established technologies in the accelerator designs. Such a restriction eliminates the possibility of using high gradient, X-band linacs or photo-cathode injectors capable of delivering multiple bunches per macro-pulse. Nonetheless several design alternatives remain. The system outlined below represents a mix of linear and circular accelerators to assure very rapid fill of the rings from a completely empty state. It represents a reasonable alternative to the baseline injection scheme of using full energy injection from a linac.

The components of the system for full energy injection into the high energy rings are illustrated in schematic fashion (not to scale) in Figure 1. An electron beam of moderate brightness is produced with an rf-gun and is subsequently accelerated to 500 MeV in a conventional, S-band, disk-loaded waveguide operating at 20 MeV/m average accelerating gradient Table 1). The power sources for the linac are standard S-band klystrons such as those presently in use to power the SLC. The linac is operated in a highly loaded, multi-bunch mode in which 5 bunches of 8 nC per bunch are accelerated with a multi-bunch energy variation of 2%. The repetition rate of the linac is limited by the design of the present SLAC modulators to 180 Hz. Once the electrons reach 0.5 GeV, they impinge upon the positron production target.

The design of the positron production target follows that of the SLC positron source. The target itself is a water-cooled, high Z (tungsten-rhenium) slab followed by a pulsed, high field solenoid to capture the positrons. The beam load on the target during the fill period of the high energy positron ring is approximately < 5 kW (assuming a safety factor of 5), significantly lower than the design value for the SLC positron source.

Based on previous practice, one expects to be able to capture ≈ 0.02 positrons per electron per GeV of incident beam energy into the acceptance of a low energy, S-band linac that brings the positrons up to 500 MeV for injection into a compact damping/accumulator ring. This transfer loss could actually be increased another factor of two if the damping ring were eliminated in favor a acummulation in the booster synchrotron.

The 500 MeV damping ring (Table 2) employs superconducting dipoles to allow a compact footprint for the ring plus a relatively short damping time ($\approx$ 5ms). The design of the positron damping ring is based on the XSLS ring presently in the engineering design phase at Brookhaven National Laboratory. The XSLS design will be modified in four significant ways. a) The dipoles will operate at <3 T as compared with the 4 T planned for XSLS. b) In contrast with XSLS, injection into the ring is at full energy; consequently, the magnets can operate at constant field. These two differences will reduce both the technical risk and the cost of the magnets. c) The straight sections of the ring will be lengthened to allow for easier injection and extraction. d) The operating frequency of the ring will be raise to 1.44 GHz to match the frequency of the booster synchrotron and main rings. By matching the radio frequency of the accumulator to that of the booster and main rings, one eliminates the need to insert a buncher section between the accumulator and the booster.

The ring will damp 5 bunches of positrons of 0.4 nC, each one of which could be produced with 20 to 30 electron beam bunches. Alternatively, the ring could be loaded with positron bunches produced with a single electron bunch and then emptied after 5 damping times. The damping scenario (see Figure 2) is strongly influenced by the availability of highly reliable kicker magnets with rapid rise and fall times ($\approx$ 50 ns). The fill scenario marginally meets the system requirement of filling the positron ring in 60 s with 25 bunches of 24 nC each.

The actual choice of the baseline damping/accumulation scenario will be made after an evaluation of the kicker design. The kicker proposed for Lawrence Berkeley Laboratory's Advanced Light Source would provide an excellent basis of this evaluation. The entire accumulation cycle is repeated at 15 Hz to match the maximum repetition rate of the booster synchrotron. For filling the electron ring a separate electron gun injects a beam into thew second 500 MeV linac. These accelerated bunches are then loaded into the synchrotron and boosted to the final energy. The filling of the electron ring is easily accomplished in $\approx$ 10 seconds.

In the scenario considered in this note, the second (2 GeV) linac of the baseline design is replaced by a booster synchrotron. In principle, the booster could double as the accumualator ring if the lattice could be designed to give an appropriately small, ($\approx$ 5 ms) damping time at the injection energy (500 MeV) into the booster. The limiting factor in the use of booster synchrotrons is that the repetition rate is limited to 15 - 30 Hz by the requirement to control sextupole fields induced in the wall of the vacuum chamber. This limitation in the repetition rate is the bottleneck in the fill scenario that makes the use of an accumulator ring essential if rapid injection is to be practical.

The estimate of the installed cost of the injection system hardware is based on established production costs for SLAC linac components, on the cost of the XSLS ring, and on an estimate of synchrotron costs from the SPEAR group. The cost of the reference design may be reduced by as much as 40% if the high gradient linac technologies including relativistic klystron power sources could be exploited at levels of 50 - 80 MeV/m. In that case the savings would likely be consumed by the cost of the research program still needed to produce reliable high gradient linacs. However, this work would have direct relevance to TeV class linear colliders.

III. Radiation control

Even in a cursory examination of the shielding and hazards control requirements for the tau charm factory, one must evaluate the hazards associated with the catastrophic loss of beam vis-a-vis those encountered during routine operation. The primary considerations include 1) the production of high energy neutrons, 2) the generation of bremsstrahlung gammas, 3) the generation of residual radioctivity in accelerator components, and 4) the production of Be and tritium that could lead to groundwater contamination.

When the positron target is operating the beam power on target will be $\approx$ 1.0 kW at 0.5 GeV. Including a safety factor of ten, one finds that a 10 cm Pb shadow shield followed by 3 meters of concrete will reduce the radiation field to $\approx$ 0.003 mR/hr just outside theshielding. This value is dominated by the high energy (> 25 MeV) neutron radiation. The most challenging shielding problem is posed by the high energy (2.5 GeV) rings. With repect to catastrophic beam loss P all of stored beam lost in a single short segment of the ring P the high energy gamma radiation yields the largest contribution to the dose just outside the shield. One finds that 10 cm of Pb shadow shield followed by 3 meters of soil will reduce the maximum single pulse dose to 25 mR. This same quantity of shielding will reduce the dose rate from routine operation to 0.001 mR/hr for a luminosity lifetime of 10000 seconds.

IV. Conclusions

From an initial analysis one concludes that the cost of an advanced linac based injection system is small compared with the cost of the main storage rings and only $\approx 60\%$ of the cost of a conventional system with a booster and accumulator ring. A linac based injection system will also offer a significant opportunity to demonstrate the practicality of linear accelerator technology with direct applicability to TeV-class linear colliders. More over no part of the injection system is limited by repetition rate as would be the case if a synchrotron booster is used . Therefore, should the luminosity lifetime fall below 1000 seconds, the system described in the reference design could still easily meet injection requirements. In particular, the positron source is readily scalable to high production rate while remaining well within the state-of-the-art. Indeed the most pressing technical challenge may the design of a detectorthat can continue to operate while the main rings are being "topped-off." A preliminary estimate of hazards control issues suggests that the degree of shielding required is such that the facility that houses the tau charm-factory could be built on the surface as long as the luminosity lifetime exceeds $\approx$1000 seconds.

Although the system described in this note appears to be suitable to constitute a full energy injection system for the τ charm factory, a final evaluation of the cost and risks of this approach vis-a-vis alternatives employing more high gradient linac technology and / or warm magnet accumulator rings will require a cost optimized, fully consistent physics design of all major components including a lattices of all circular accelerator components and of a transfer beamline matched to the characteristics of the high energy rings. This physics design should include a complete fill scenario for each of the high energy rings including a switching schedule for the the kicker magnets. Moreover, the design must be iterated with respect to its impact on the operation of the collider.

References

[1] J. Jowett, Initial Design of a τcharm Factory at CERN, CERN LEP-TH/87-56, Dec., 1987.

Table 1. Characteristics of S-band linac

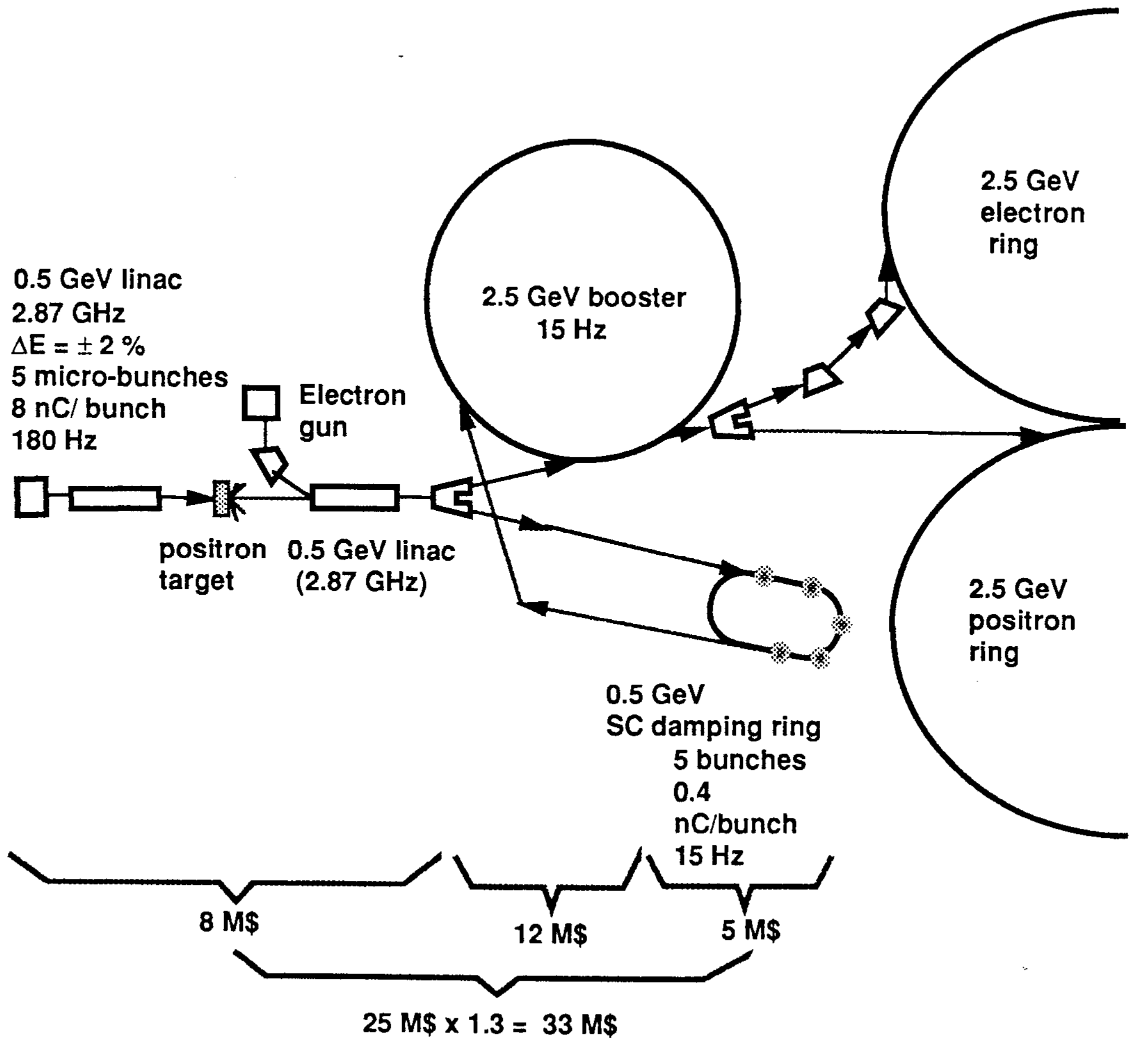
	**Italics denote inputs*	
	Beam parameters	
*	*Energy (GeV)*	0.50
*	*Peak current (kA)*	0.50
*	*Pulse length (ps)*	15.0
*	*Norm Emit (mm-rad)*	0.010
*	*rep rate (Hz)*	180
	Pulse length (mm)	- 5.0
	N-part	4.5e+10
	n bunches	5
	min. bunch space (ns)	5.23
	in wavelengths	16
	Derived values	
	Gamma	9.79E+02
	Emittance (m-rad)	1.02e-08
	Pulse energy (J)	3.60
	Macro-pulse (J)	18.0
	E-beam power (kW)	3.2
	Brightness (a/m2-r2)	1.0e+13
	Wakes	
*	*Dipole de-Q*	100
	single bunch	
	wt (v/C/m^2)	1.9e+15
	Landau p/p (%)	0.73
	L to correct (m)	0.3
	-y (m)	122.1
	multi-bunch wake	
	Q*(1/f) (s)	4.9
	Wmb (V/C/m^2)	2.7e+15
	Landau-m -p %	1.02
	L to correct (m)	0.4
	Longitudinal wake	
	Wake at 0 V/C/m	1.3e+14
	non-lin p/p accel	1.13
	Ph to corr. Landau	-0.9
	Linac focussing	
	Focus system	FODO
*	*Linac focus (T)*	0.5
*	*Quad. fraction*	0.05
	# of quads	13

	Accelerator rf	
	RF (GHz)	2.87
*	*rf-efficiency*	0.65
*	*Iris a (mm)*	13.94
*	*Fill T/atten . T*	0.30
*	*Bunch (full phase)*	15.5
*	*Fill fraction*	0.94
	wavelength(mm)	104.5
	iris/lambda	0.13
	cavity/iris	3.0
	Cavity size (mm)	41.4
	uncor elastance	6.8e+13
	v-group/c	0.025
	atten. time (s)	1.5e-06
	Q	13950
	Energy/m	7.8e+00
	E-max (MV/m)	44
	E-accel (MeV/m)	20.5
	Active length (m)	26.0
	Gradient (MeV/m)	19.2
	Fill length (m)	3.42
	Number of sections	8
	cavities/section	98
	rf P (MW/m)	17
	rf P (MW/section)	62
	struc. efficiency	0.75
	loading %	2.5
	t-refill(ns)	5.1
	rf-supply (ns)	453
	Beam efficiency %	8.8
	Total rf (TW)	4.5E-04
	Tolerances	
	Alignment (m)	1374.8
	Vibration tol. (m)	13.5
	-p to focus(%)	1.04
	Multi-bunch E(%)	0.02
	N-max in -p	24
	Wall load (W/cm2)	0.1

program revision - 5/5/89

Table 2. Characteristics of superconductiong ring

Damping ring			
* *DBA or FODO*	fodo	* *RF freq (GHZ)*	1.44
* *Dipole field (T)*	2.9	* *phase advance/cell*	1.20
* *Vert/horiz mixing*	0.05	* *Jx=Jy*	1.05
* *Dipole fraction*	0.25	* *aperture (m)*	0.1
* *beta-x/beta-y*	0.5	* *Quad fraction*	0.2
* *B-wiggler (T)*	0.001	* *Quad field (T)*	1.4
* *Wiggler fraction*	0	bunch spacing (m)	2.9
* *Wiggle period (cm)*	5	number of bunches	5
Energy (GeV)	0.5	Jz	1.9
gamma	978	Jx+mix*Jy	1.05
N-ring	1.1E+10	B-local/¡B¿	1.07
B-rho	1.67	Rev. freq	2.1E+07
Bend radius (m)	0.5741	harmonic # - h	6.9E+01
Ring Radius (m)	2.3	E loss/turn	9.6E+03
Circumference (m)	14.4	Rf kVolts/turn *h	6.7E+02
Dipole length (m)	3.6	Momentum compact	0.248
Drift lengths (m)	7.9	nu-synch	7.3E-03
L-dipole (m)	0.41	p in ring	6.2E-04
Dipole number	8	length in ring (m)	4.8E-02
K-wiggle	0.0	emit-z	0.03
T-wig / T-dipole	1.00	I(A)	0.04
Damping t (ms)	**4.99**	P-synch (kW)	0.4
emit	**3.7E-04**	U-crit (keV)	0.54
beta-x	1.37	U-wig (keV)	0.05
beta-y	2.73	Z/n (Ohms)	**476.58**
Tune Qx	1.68	n	47.4
Tune Qy	0.8	Z (Ohms)	22575.2
Dispersion	8.1E-01	Fill time (s)	0.05



Injection system with accumulator and booster for tau/charm factory

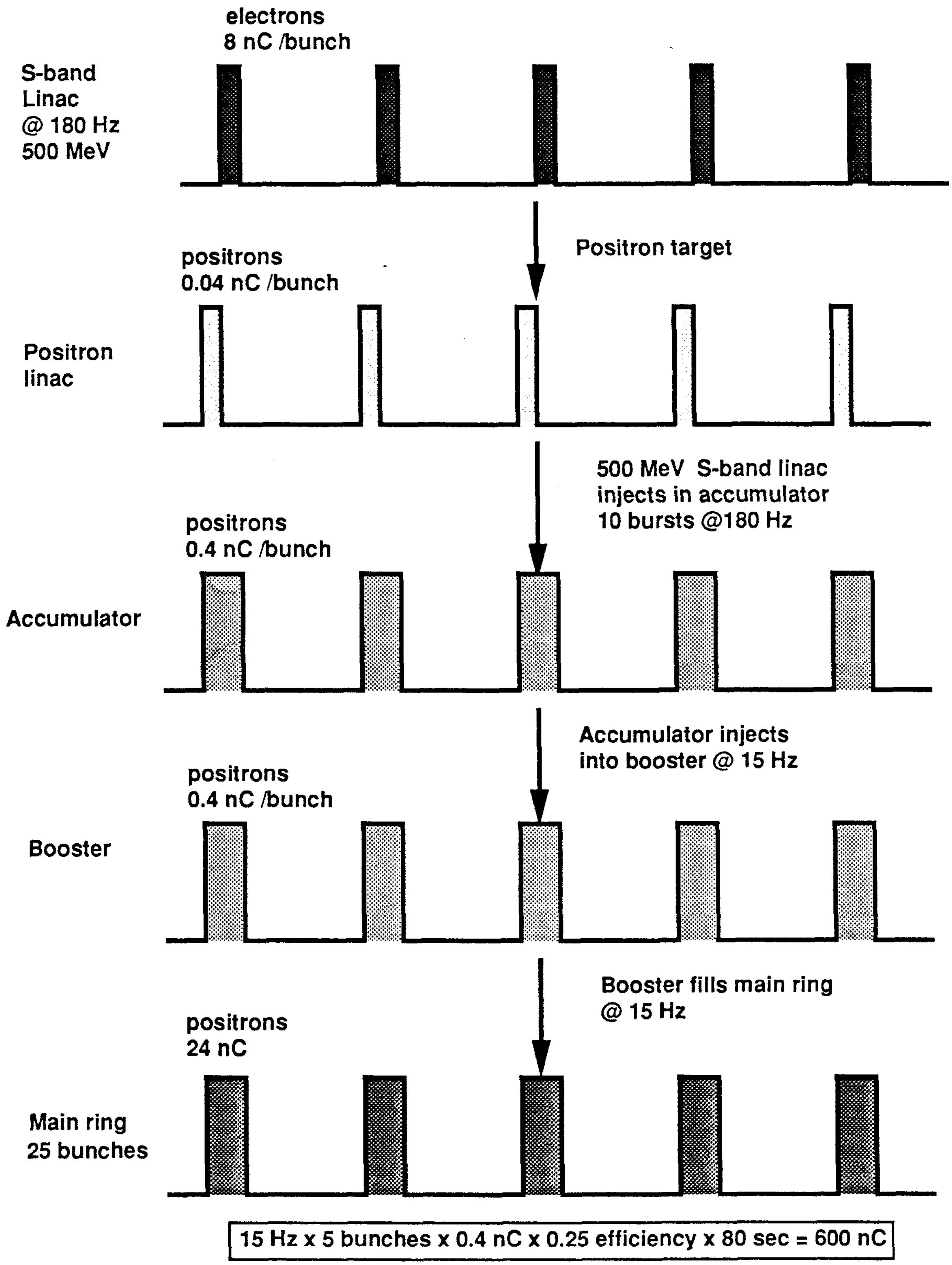


Fig. 2. Injection scenario with accumulator ring