DAΦNE TECHNICAL NOTE
INFN - LNF, Accelerator Division

Frascati, Dec. 20, 1991
Note: **I-6**

INJECTION INTO DAΦNE AND TIMING REQUIREMENTS FOR THE LINAC-ACCUMULATOR-MAIN RINGS COMPLEX

M. Preger

INTRODUCTION

The strategy of injection into DAΦNE has been outlined in the DAΦNE Technical Note I-1[1], where a preliminary lattice for the accumulator is described, together with the requirements on the Linac output current. The structure of the Linac is given in LC-1[2], while L-1[3] is a preliminary description of the main ring lattice. A first study of injection into the main ring is given in I-2[4] for this lattice. The development of the project introduced some modifications both in the main ring and in the accumulator lattices, and the updated structures are described in L-4[5], I-4[6] (which presents the injection scheme into the accumulator) and I-5[7]. In this Note we set the requirements for the pulsed elements in the DAΦNE main rings, based on the updated lattice, and the structure of the timing system required to synchronize the operation of the Linac, accumulator and main ring complex.

INJECTION INTO THE DAΦNE MAIN RINGS

The lattice of the "long" arc[5] has been designed to optimize injection of the beam from the accumulator in its central symmetry point. A 3.4 m free straight section is available between quadrupoles QL1 for the installation of the septum, while two kickers can be placed into the 1.9 m straight sections DL3 (see Table I), where the horizontal betatron phase difference from the center of the septum straight is exactly $\pi/2$ at a distance of 57 cm from quadrupole QL3. No sextupoles are included within this half betatron wavelength, thus avoiding the necessity of performing non linear tracking simulations to establish the required apertures. The only drawback of this choice for the injection point is the rather large value of the dispersion (≈ -1 m) at the septum, but this disadvantage is not harmful, because of the small energy dispersion of the beam from the accumulator. Table II summarizes the accumulator and main ring parameters relevant to injection.

Table I - Magnetic structure of half "long" straight section

Name	Type	Length (m)	Gradient (T/m)	Gradient (T/m^2)
DL6	Drift	0.4		
SDL1	Sextupole	0.2		8.50
DL5	Drift	0.8		
QL4	D-quad	0.3	- 1.92	
DL4	Drift	0.5		
QL3	F-quad	0.3	6.75	
DL3	Drift	1.9		
QL2	D-quad	0.3	- 4.48	
DL2	Drift	0.5		
QL1	F-quad	0.3	4.00	
DL1	Drift	1.7		

The second half of the "long" straight is symmetric with respect to the end of DL1.

Table II - Accumulator and main ring parameters

Accumulator emittance (mm.mrad)	0.294
Accumulator r.m.s. energy spread (%, Z/n = 0)	0.042
Accumulator r.m.s. energy spread(%, Z/n = 4 Ω)	0.085
Accumulator r.m.s. bunch length (cm, Z/n = 0)	2.3
Accumulator r.m.s. bunch length (cm, Z/n = 4 Ω)	4.9
Main ring emittance (mm.mrad)	1.0
β function at septum straight section center (m)	13.2
Dispersion at septum straight section center (m)	-1.0
Horizontal r.m.s. beam size at straight section center (mm)	3.7
β function at kicker position (m)	0.8
R.F. bucket length (cm)	81.4
R.F. energy acceptance (%, Z/n = 2 Ω, V_{RF} = 254 KV)	1.1

The following calculations assume the septum endpoint at the end of DL1 (in the center of the long 3.4 m straight section). However, due to the high value of the horizontal betatron function (≈13 m), the actual septum position can be set anywhere in the straight sections without changing injection parameters appreciably.

If the transport channel from the accumulator to the main ring is achromatic, its optimum horizontal betatron function at the septum endpoint, in order to minimize the residual oscillation amplitude of the injected beam can be found from:

$$y^4 + (A/2\sqrt{\varepsilon})\, y^3 = \beta^2/2 \qquad\qquad \beta_{opt} = y^2$$

where ε is the emittance of the incoming beam, β the horizontal betatron function of the main ring at the septum position, and A is the sum of the distance between the already stored beam and the septum plus the septum thickness. Assuming ±3 standard deviations in horizontal amplitude to be accepted from the accumulator, 4 standard deviations of the stored beam as the minimum distance between the displaced orbit and the septum, and 4.2 mm for the septum thickness (as in the accumulator), we find

$$\beta_{opt} = 4.9 \text{ m}$$

and 7 mm for the full width of the beam from the accumulator. Taking into account only the betatron motion, the residual oscillation amplitude r of the injected beam at the septum position comes out to be

$$r = 26 \text{ mm}$$

well within the dynamic aperture (≈43 mm) for synchronous particles [5].

A small contribution to the residual amplitude comes from the dispersion at the injection point. If we want to accept ±3 σ's in the energy distribution of the beam from the accumulator, the synchrotron oscillations will contribute 2 additional millimiters to the value of ρ (see Table II). A further increase in the synchrotron amplitude comes from the length of the injected bunch, which may reach 5 cm (r.m.s.), if the accumulator impedance will be around 4 Ω. Assuming a safety factor of two on the longitudinal acceptance, and including the energy distribution term, the total increase in r can be estimated in ≈6 mm, so that the total foreseen amplitude reaches 32 mm at the septum, and scales obviously in the rest of the ring with the square root of the betatron function and the dispersion.

From the above discussion, it is clear that the inner side of the septum cannot be less than 32 mm away from the reference orbit in the straight section. However, the requirement for a comfortable beam lifetime, mainly dependent on the Touscheck effect, asks for a minimum aperture of 40 mm at the septum position[5]. In this case, in order to minimize the amplitude of the residual oscillation, the closed orbit perturbation created by the kickers must be displaced by $X_b \approx 25$ mm from the central orbit. The required angle in the kickers is given by

$$\delta = X_b / \sqrt{\beta_k \beta_s} = 7.8 \text{ mrad}$$

corresponding to an integrated bending field of 133 G.m. It is clear that a smaller angle in the kickers will compensate for closed orbit distortions and field or timing errors in the kickers at the expense of a larger residual oscillation amplitude of the injected particles. Fig. 1 shows the trajectories of the stored and injected beams through half of the long straight, starting from the septum endpoint and followed up to the beginning of the first bending magnet downstream the injection point.

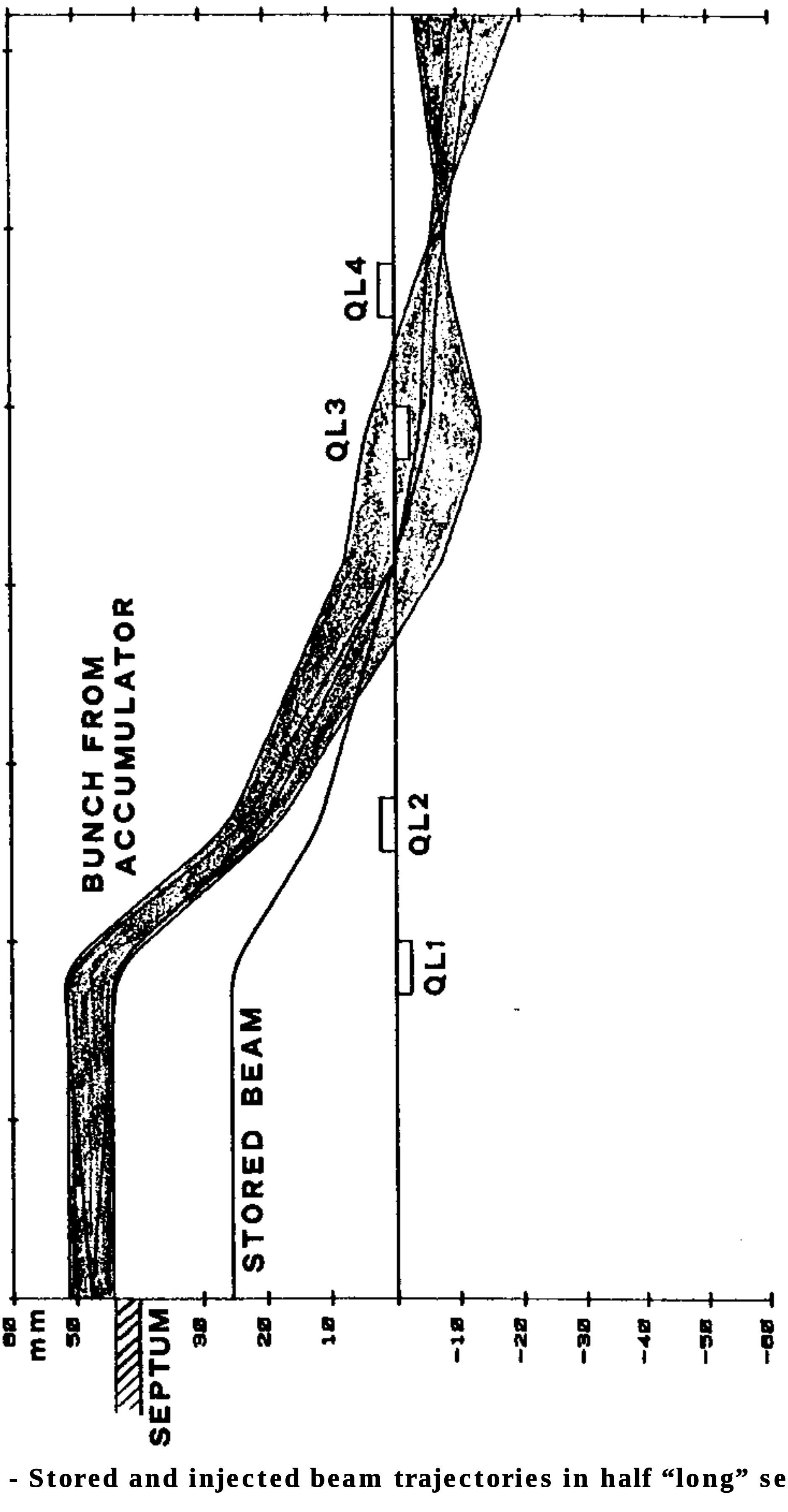

Fig. 1 - Stored and injected beam trajectories in half "long" section.

TIMING OF THE LINAC-ACCUMULATOR-MAIN RINGS COMPLEX

The injection system for the DAFNE main rings is designed[1] to provide full flexibility in the bunch pattern: it is therefore necessary to synchronize the Linac, accumulator and main ring pulsed elements in order to fill any desired main ring bucket. For this reason the accumulator length has been chosen as exactly 1/3 or the main ring one, so that a single bunch stored in the booster can be transferred at each turn into one out of three equidistant buckets of the main ring. The accumulator R.F. harmonic number is 8, and therefore 24 buckets of the main ring can be filled by shifting the relative phase of the Linac gun with respect to the accumulator cavity. However, 120 main ring buckets should be independently filled, and this asks for the capability of shifting also the phase of the accumulator cavity with respect to the main ring one, at a frequency of ≈1 Hz.

The main ring revolution frequency, which can easily be derived from the cavity R.F. generator, will act as a clock for the whole system. The accumulator R.F. system, running at the 24th harmonic of the clock will be phase-locked to the main ring one, and its phase must be shifted with respect to the clock in steps of 2.72 ns during the damping time before extraction (≈100 ms) if more than 24 bunches are to be injected or if the desired bunch pattern is not in coincidence with one of the 8 accumulator buckets. Five steps are necessary to fill all the main ring buckets. The trigger of the Linac gun must be locked to the accumulator R.F. generator, with the capability of reaching any of the 8 accumulator buckets.

The acceptance of the booster, due to high cavity voltage and low energy of the beam, is almost one bucket length in phase (13.6 ns) and ±2.3% in energy spread. A 10 nsec, ±1.5% bunch from the Linac will be accepted in the longitudinal phase space with more than 95% efficiency. The arrival time of the bunch at the injection septum is not critical (within ± 1 nsec) because the loss on one side of the bucket is partially compensated by the gain on the other one.

The tolerance on the jitter, of the accumulator bunch, to be injected into the main ring depends on the operation mode of DAFNE: a very strict tolerance is necessary if one wants to maintain the luminosity during the "topping up" procedure, where only a fraction of the total current is frequently refilled to maintain a very high average luminosity: in this case the allowed time jiiter is of of the order of β_y/c (≈0.1 ns), to avoid crossing of the injected bunch with the other beam where the vertical betatron function is large, and therefore the stronger tune shift could drive to bunch loss. If, instead, the beams will be separated, by means of R.F. phase shift between the two rings or vertical closed orbit distortion, the limit is given by the half-bucket length (≈1 ns). However, this limit must be reduced, if off-energy (or off-phase) injection of a single bunch can excite multibunch instabilities which cannot be corrected by the longitudinal feedback system.

REFERENCES

[1] M. Preger: "A positron and electron accumulator for DAΦNE", DAΦNE Technical Note I-1 (8/11/1990).

[2] S. Kulinski, R. Boni, B. Spataro, M. Vescovi, G. Vignola: "The linear accelerator for the DAΦNE injection system", DAΦNE Technical Note LC-1 (11/2/1991).

[3] M. Bassetti, M.E. Biagini, C. Biscari, S. Guiducci, M.R. Masullo, G. Vignola: "High emittance lattice for DAΦNE", DAΦNE Technical Note L-1 (30/10/1990).

[4] M. Preger - "Injection scheme for the DAΦNE main ring", DAΦNE Technical Note I-2 (15/11/1990).

[5] M.E. Biagini, S. Guiducci, M.R. Masullo, G. Vignola: “DAΦNE lattice update”, DAΦNE Technical Note L-4 (2/12/1991).

[6] S. Guiducci, M.R. Masullo, C. Milardi, M. Preger: "DAΦNE accumulator update - 2", DAΦNE Technical Note I-4 (1/10/1991).

[7] M. Masullo, M. Preger: "A new working point for the DAΦNE accumulator", DAΦNE Technical Note I-5 (3/12/1991).