**DAΦNE TECHNICAL NOTE**
INFN - LNF, Accelerator Division

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Frascati, Nov. 8, 1990
Note: **I-1**

# A POSITRON AND ELECTRON ACCUMULATOR FOR DAΦNE

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## 1 - INTRODUCTION

The injection system for DAΦNE, the Frascati Φ-factory project, must be designed as a very powerful and flexible device, capable of filling the main ring with a number of positrons and electrons in the range between $2 \cdot 10^{12}$ and $10^{13}$ in few minutes, with any reasonable combination of bunches in the main ring. In this paper I propose an injection scheme based on a small ring to be used as a positron/electron accumulator between the Linac and the main ring. This arrangement, successfully operating in the largest electron-positron storage rings in the world (LEP and PETRA, while PEP can be injected directly from SLAC) has recently been proposed also for Adone [1] in order to speed up positron injection.

The use of an accumulator instead of direct injection from a Linac, in the case of injection into the Frascati Φ-factory, has the following advantages:

- Complete filling of the ring from a Linac (50 Hz, 5 minutes) requires $\approx 1.5 \cdot 10^4$ injection pulses; this is a severe constraint on the allowed loss from the stored beam at each injection pulse ($<<10^{-4}$) to avoid saturation: with an accumulator running at 50 Hz with extraction and injection into the main ring at 1 Hz the allowed loss is 300 times larger in the accumulator and 50 in the main ring.

- The R.F. frequency in the accumulator can be smaller than in the main ring, where a large number of very short bunches must be realized to optimize luminosity, so that a larger longitudinal acceptance can be obtained.

- The magnetic structure of the accumulator can be easily optimized for injection: the dispersion function can be kept small all over the machine, so that its energy acceptance can be large.

- The beam injected from the accumulator into the main ring will have very small emittance, bunch length and energy spread, thus substantially decoupling the main ring from injection requirements on the physical and dynamic aperture.

It has been shown [1] that the magnetic structure of the storage ring ACO, in use at Orsay for high energy physics in the 60's, and after also successfully employed for synchrotron radiation production and for free electron laser experiments, can match the requirements of a short positron/electron accumulator. Its lattice is very flexible and the optical functions do not change very much when the length of the straight sections and of the arcs are varied on a rather wide range, keeping the betatron tunes constant.

In order to provide easy synchronization between the accumulator and the main ring, a judicious choice for the accumulator total length is an integer submultiple of the main ring one. This is not strictly necessary, because suitable electronic systems can be provided to mantain synchronism if the ratio of the two lengths is a rational number. However, I think that if no other constraint come out to be important, this may be an important advantage for the reliability of the system. In a similar way, it might be easier for the design of the two R.F. systems that the two frequencies are chosen in an integer ratio. The proposed length of the main ring [2] is 94.56 m, with an R.F. system running on the 120th harmonic at 380.44 MHz. With this harmonic a wide choice of equidistant bunches is available in the main ring. A possible solution for the accumulator is therefore a total length of 31.52 m (1/3 of the main ring) with an R.F. system at 76.09 MHz (1/5 of the $\Phi$-factory system). This total length ensures sufficient space in the accumulator to accommodate all the injection elements required to store (separately) both electrons and positrons.

## 2 - THE ACCUMULATOR LATTICE

The original lattice of ACO has been modified to match the requirements described in the introduction. Its original circumference of 22.01 m has been increased to 31.52 m, mainly by increasing the 4 straight section length to 3.85 m. As shown in Fig. 1, this allows easy accommodation of 4 powerful kickers for injection and extraction of both beams, a single 76.09 MHz R.F. cavity and two septa, leaving enough additional space for feed-back systems (if necessary) and/or diagnostic and correction elements. The original arc structure has also been modified, leaving more space between the quadrupoles for sextupoles to correct chromaticity.

The periodicity of the linear lattice is 4, with 8 symmetry points at the beginning and center of each period. The horizontal betatron tune is determined by the requirements of a small dispersion in the injection and R.F. straight sections and of a convenient phase advance between the kickers and the septa. A good compromise is $Q_x = 2.89$. There is no particular constraint on the vertical tune: the choice of $Q_y = 1.13$ does not increase quadrupole gradients too much, keeps the chromaticity low and ensures satisfactory betatron function separation in the arcs for chromaticity correction.

Fig. 2 shows the optical functions in a single accumulator period. A gradient bending magnet (field index n=0.5) helps significantly in keeping the betatron function behaviour smooth; with this choice the two betatron damping times are equal (19.7 msec). The dispersion function is less than 20 cm in the straight section, and never exceeds 80 cm.

A couple of 20 cm sextupoles is installed in each period, as shown schematically in Fig.1. The required gradient is not large, but the degree of symmetry is not as high as that of the linear lattice. Should tracking simulations show that a symmetric arrangement is better, the number of sextupoles can be doubled.

Table I is a parameter list for the accumulator, Table II provides a MAD output for the lattice and Table III shows the requirements for the magnetic elements of the structure.

## 3 - INJECTION AND EXTRACTION

In order to ensure injection into any possible bunch configuration, single bunch injection is foreseen. This choice makes the design of the Linac system easy: a single prebunching system at the Linac accelerating frequency is necessary, and the macrobunch length (≈10 ns) allows the use of a SLED system to improve the accelerating gradient. Moreover, a similar pulse length is used in other injector Linacs (LEP, PETRA) so that much experience is available on such accelerators. Single bunch injection relaxes also requirements on the pulsed elements in the accumulator and the main ring, since no long flat tops with very short rise and fall times are necessary.

Fig. 1 shows the schematic diagram of the accumulator injection and extraction systems. The short ring circumference makes the installation of 4 separate septa for injection and extraction of electrons and positrons rather difficult. A nice solution is to extract positrons from the electron injection channel and vice-versa. In this case a symmetrical arrangement for the kickers is necessary with different amplitudes for injection and extraction. During the phase of positron injection, the particles are deflected on the left by the separator magnet M1 (see Fig. 1); magnet M2 is off, so that the beam reaches septum S1 after passing through M3. The four kickers are fired at a proper trigger sequence to displace the already stored beam towards S1 and to "capture" the beam coming from the Linac, which reduces by 1/e its original emittance in a damping time (≈20 msec) before the next pulse is injected. The frequency of the injection pulses is 50 Hz, and 45 pulses are injected into the accumulator. Five damping times are then left to completely damp emittance and energy spread of the stored beam down to the equilibrium values in the accumulator, and then a single kick from K3 and K4 extracts the beam through septum S2. Magnet M4 is switched off and M5 bends the extracted beam on the the injection channel to the main ring. Electrons instead are bent on the right by M1 and reach S2 through M4. The four kickers are powered with different fields and time sequence from the previous ones, but always with the same field direction. The pulse rate, due to the higher current from the linac, can be lower than 50 Hz. Electrons are then extracted from S1, bent through M3 and M2 (with M5 off) and transported to the main ring.

The aperture of the accumulator is mainly dictated by positron injection requirements. Assuming a full emittance of 10 mm.mrad from the Linac with an energy spread of ± 1%, and a septum thickness of 2 mm, the optimum position for the septum comes out to be 20 mm from the central orbit, with the stored beam passing at ≈5 mm (6 $\sigma$'s) from the septum. This distance provides sufficient acceptance for the beam coming from the linac, with a reasonable safety margin for closed orbit errors due to misalignment and to amplitude and phase errors in the kickers. The closed orbit due to the kickers is shown in Fig. 3, together with the extraction trajectory, and the corresponding integrated fields in the kickers in Table IV. The horizontal aperture where the betatron function and the dispersion are maximum is 3 cm. Tracking studies, including the effect of sextupoles, should be performed in order to determine the necessary aperture in the region from the injection septum to the kickers; however, it seems reasonable to assume that a horizontal free aperture of ± 40 mm will be sufficient to accommodate injection efficiently. The requirements on the vertical aperture are less demanding, since the maximum beam size, with the same emittance, will be ≈±10 mm.

In order to estimate the required current from the Linac, it is necessary to make assumptions on the injection, transport and extraction efficiencies. Table V shows a conservative set of parameters, mainly based on data available from similar injection systems. Given the desired maximum stored current in the rings ( ≈ $10^{13}$ particles in each one), and a reasonable injection time of 5 minutes, Table VI gives the charges and number of particles at each step of the injection procedure. The required current from the linac gun, in a 10 ns pulse, comes out to be ≈ 13 A. The maximum stored current in the accumulator is ≈ 70 mA.

## REFERENCES

[1] M. Preger - "Performance of ACO as a positron accumulator for Adone" - Divisione Acceleratori, Memorandum Interno G-96 (1989).

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

# TABLE I - PARAMETERS OF THE ACCUMULATOR

| | |
|---|---|
| Circumference (m) | 31.52 |
| Straight section length (m) | 3.85 |
| Horizontal betatron wavenumber | 2.89 |
| Vertical betatron wavenumber | 1.13 |
| Dispersion at Straight Section Center (SSC*) (m) | 0.19 |
| Horizontal $\beta$ at SSC (m) | 2.51 |
| Vertical $\beta$ at SSC (m) | 3.72 |
| Maximum dispersion (m) | 0.80 |
| Maximum horizontal $\beta$ (m) | 4.38 |
| Maximum vertical $\beta$ (m) | 11.12 |
| Horizontal betatron damping time (msec) | 19.70 |
| Vertical betatron damping time (msec) | 19.70 |
| Synchrotron damping time (msec) | 9.85 |
| Momentum compaction | 0.059 |
| Natural emittance (m.rad) | $2.66 \times 10^{-7}$ |
| R.m.s. energy spread | $4.16 \times 10^{-4}$ |
| Horizontal r.m.s. beam size at injection (mm, no coupling) | 0.82 |
| Vertical r.m.s. beam size at injection (mm, full coupling) | 0.70 |
| Horizontal chromaticity (sextupoles off) | -4.43 |
| Vertical chromaticity (sextupoles off) | -4.08 |
| R.F. frequency (MHz) | 76.09 |
| R.F. Voltage (KV) | 100 |
| Harmonic number | 8 |
| R.F. energy acceptance (%) | ±1.55 |
| r.m.s. bunch length (cm) | 3.2 |

(*) SSC = Straight Section Center

TABLE II – MAD output for the accumulator lattice

```
"MAD" VERSION 4.03

DATE AND TIME OF THIS RUN:      00/00/00      00:00:00

INPUT STREAM AND MESSAGE LOG:

            TITLE!
            positron accumulator for dafne

            ! PHYSICAL ELEMENTS FOLLOW

            DRIFT,L1,L=1.9261
            DRIFT,L2,L=0.35

            QUAD,QF1,L=0.30,K1=4.884852
            QUAD,QD1,L=0.15,K1=-5.284224

            SBEND,BB,L=0.86394,ANGLE=0.7854,K1=-.4132

            ! LATTICE STRUCTURE FOLLOWS
            LINE,HCELL=(L1,BB,L2,QF1,L2,QD1)
            LINE,CELL=(HCELL,-HCELL)
            LINE,MACC=(4*CELL)
```

```
positron accumulator for dafne                                                  "MAD" VERSION: 4.03      RUN: 00/00/00  00:00:00
TWISS PARAMETERS FOR BEAM LINE "MACC"             DELTA(P)/P =     0.000000     SYMM = F                                 PAGE     1
------------------------------------------------------------------------------------------------------------------------------------
    ELEMENT SEQUENCE      I                 H O R I Z O N T A L             I                 V E R T I C A L
POS.  ELEMENT OCC.    DIST I    BETAX  ALFAX   MUX    X(CO)  X'(CO) DX     DX'  I   BETAY  ALFAY   MUY    Y(CO)  Y'(CO) DY     DY'
NO.   NAME    NO.     [M]  I    [M]            [2PI]  [MM]   [MRAD] [M]         I   [M]            [2PI]  [MM]   [MRAD] [M]
------------------------------------------------------------------------------------------------------------------------------------
BEGIN MACC       1    0.000     2.509  0.000   0.000  0.000  0.000  0.194  0.000    3.719  0.000   0.000  0.000  0.000  0.000  0.000
BEGIN CELL       1    0.000     2.509  0.000   0.000  0.000  0.000  0.194  0.000    3.719  0.000   0.000  0.000  0.000  0.000  0.000
BEGIN HCELL      1    0.000     2.509  0.000   0.000  0.000  0.000  0.194  0.000    3.719  0.000   0.000  0.000  0.000  0.000  0.000
    1 L1         1    1.926     3.988 -0.768   0.104  0.000  0.000  0.194  0.000    4.716 -0.518   0.076  0.000  0.000  0.000  0.000
    2 BB         1    2.790     4.217  0.530   0.136  0.000  0.000  0.495  0.680    4.308  0.941   0.105  0.000  0.000  0.000  0.000
    3 L2         1    3.140     3.883  0.424   0.150  0.000  0.000  0.733  0.680    3.703  0.788   0.119  0.000  0.000  0.000  0.000
    4 QF1        1    3.440     2.250  4.200   0.165  0.000  0.000  0.767 -0.462    5.006 -5.749   0.131  0.000  0.000  0.000  0.000
    5 L2         2    3.790     0.325  1.300   0.232  0.000  0.000  0.606 -0.462    9.863 -8.129   0.139  0.000  0.000  0.000  0.000
    6 QD1        1    3.940     0.137  0.000   0.361  0.000  0.000  0.571  0.000   11.133  0.000   0.141  0.000  0.000  0.000  0.000
END   HCELL      1    3.940     0.137  0.000   0.361  0.000  0.000  0.571  0.000   11.133  0.000   0.141  0.000  0.000  0.000  0.000
BEGIN HCELL      2    3.940     0.137  0.000   0.361  0.000  0.000  0.571  0.000   11.133  0.000   0.141  0.000  0.000  0.000  0.000
    7 QD1        2    4.090     0.325 -1.300   0.490  0.000  0.000  0.606  0.462    9.863  8.129   0.143  0.000  0.000  0.000  0.000
    8 L2         3    4.440     2.250 -4.200   0.557  0.000  0.000  0.767  0.462    5.006  5.749   0.151  0.000  0.000  0.000  0.000
    9 QF1        2    4.740     3.883 -0.424   0.572  0.000  0.000  0.733 -0.680    3.703 -0.788   0.163  0.000  0.000  0.000  0.000
   10 L2         4    5.090     4.217 -0.530   0.586  0.000  0.000  0.495 -0.680    4.308 -0.941   0.177  0.000  0.000  0.000  0.000
   11 BB         2    5.954     3.988  0.768   0.618  0.000  0.000  0.194  0.000    4.716  0.518   0.206  0.000  0.000  0.000  0.000
   12 L1         2    7.880     2.509  0.000   0.723  0.000  0.000  0.194  0.000    3.719  0.000   0.282  0.000  0.000  0.000  0.000
END   HCELL      2    7.880     2.509  0.000   0.723  0.000  0.000  0.194  0.000    3.719  0.000   0.282  0.000  0.000  0.000  0.000
END   CELL       1    7.880     2.509  0.000   0.723  0.000  0.000  0.194  0.000    3.719  0.000   0.282  0.000  0.000  0.000  0.000
END   MACC       1   31.520     2.509  0.000   2.890  0.000  0.000  0.194  0.000    3.719  0.000   1.130  0.000  0.000  0.000  0.000
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TOTAL LENGTH =        31.520320         QX            =          2.890055       QY            =          1.129940
                                        QX'           =         -4.433579       QY'           =         -4.076365
ALFA         =         0.589095E-01     BETAX(MAX)    =          4.217159       BETAY(MAX)    =         11.133429
GAMMA(TR)    =         4.120096         DX(MAX)       =          0.767377       DY(MAX)       =          0.000000
------------------------------------------------------------------------------------------------------------------------------------
... END OF "TWISS" COMMAND, ELAPSED CPU TIME =       0.000 SECONDS
```

## TABLE III - MAGNETIC ELEMENTS

**Bending magnets**

| | |
|---|---|
| Number | 8 |
| Bending angle (deg) | 45 |
| Bending radius (m) | 1.1 |
| Maximum center field (T, 510 MeV) | 1.55 |
| Magnetic length (m) | 0.864 |
| Field index | 0.5 |
| Maximum gradient (T/m, 510 MeV) | 0.70 |
| Gap (cm) | 5 |

**Quadrupoles**

| | |
|---|---|
| Number | 12 |
| Magnetic length (m) | 0.3 |
| Maximum gradient (T/m, 510 MeV) | 8.78 |
| Bore radius (cm) | 5 |

**Sextupoles (for $Q'_x = Q'_y = +1$)**

| | |
|---|---|
| Number | 8 |
| Magnetic length (m) | 0.2 |
| Maximum gradient (T/m$^2$, 510 MeV) | 39 |
| Bore radius (cm) | 5 |

## TABLE IV - PULSED ELEMENTS

| | **K1** | **K2** | **K3** | **K4** | **f (Hz)** |
|---|---|---|---|---|---|
| Positron injection | -3.85 mrad<br>65.5 Gm | -2.04 mrad<br>34.7 Gm | -2.04 mrad<br>34.7 Gm | -3.85 mrad<br>65.5 Gm | 50 |
| Positron-extraction | - | - | -6.49 mrad<br>110.3 Gm | -3.40 mrad<br>57.8 Gm | 1 |
| Electron injection | -2.04 mrad<br>34.7 Gm | -3.85 mrad<br>65.5 Gm | -3.85 mrad<br>65.5 Gm | -2.04 mrad<br>34.7 Gm | 10-50 |
| Electron extraction | - | - | -3.40 mrad<br>57.8 Gm | -6.49 mrad<br>110.3 Gm | 1 |

## TABLE V - TRANSPORT AND INJECTION EFFICIENCIES

| | |
|---|---|
| Transport from gun to converter | 0.4 |
| Conversion from electrons to positrons | 0.008 |
| Transport from converter to positron accumulator | 0.9 |
| Injection into positron accumulator | > 0.5 |
| Extraction from positron accumulator | 0.9 |
| Transport and injection into main ring | 0.8 |

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## TABLE VI - NUMBER OF PARTICLES

| | Number | Charge (nCoul) |
|---|---|---|
| Positrons stored into main ring | $1.08 \times 10^{13}$ | 1733.00 |
| Positrons stored into main ring/pulse | $3.61 \times 10^{10}$ | 5.78 |
| Positrons extracted from accumulator/pulse | $4.51 \times 10^{10}$ | 7.22 |
| Positrons injected into accumulator/pulse (45 pulses) | $1.11 \times 10^{9}$ | 0.18 |
| Positrons at the end of the Linac/pulse | $2.22 \times 10^{9}$ | 0.36 |
| Positrons after converter/pulse | $2.48 \times 10^{9}$ | 0.40 |
| Electrons before converter/pulse | $3.09 \times 10^{11}$ | 49.53 |
| Electrons from the gun/pulse | $7.74 \times 10^{11}$ | 123.81 |

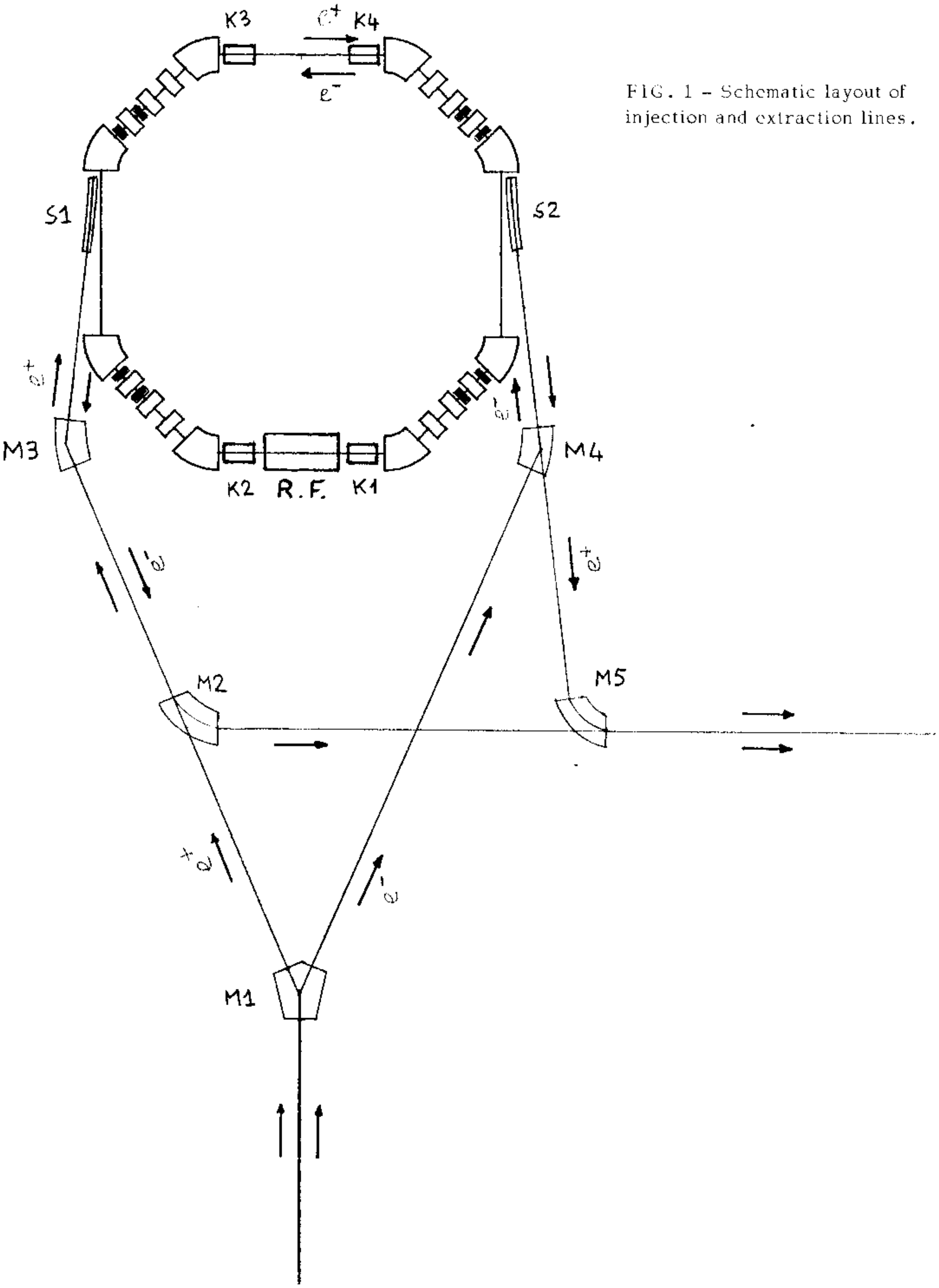

FIG. 1 - Schematic layout of injection and extraction lines.

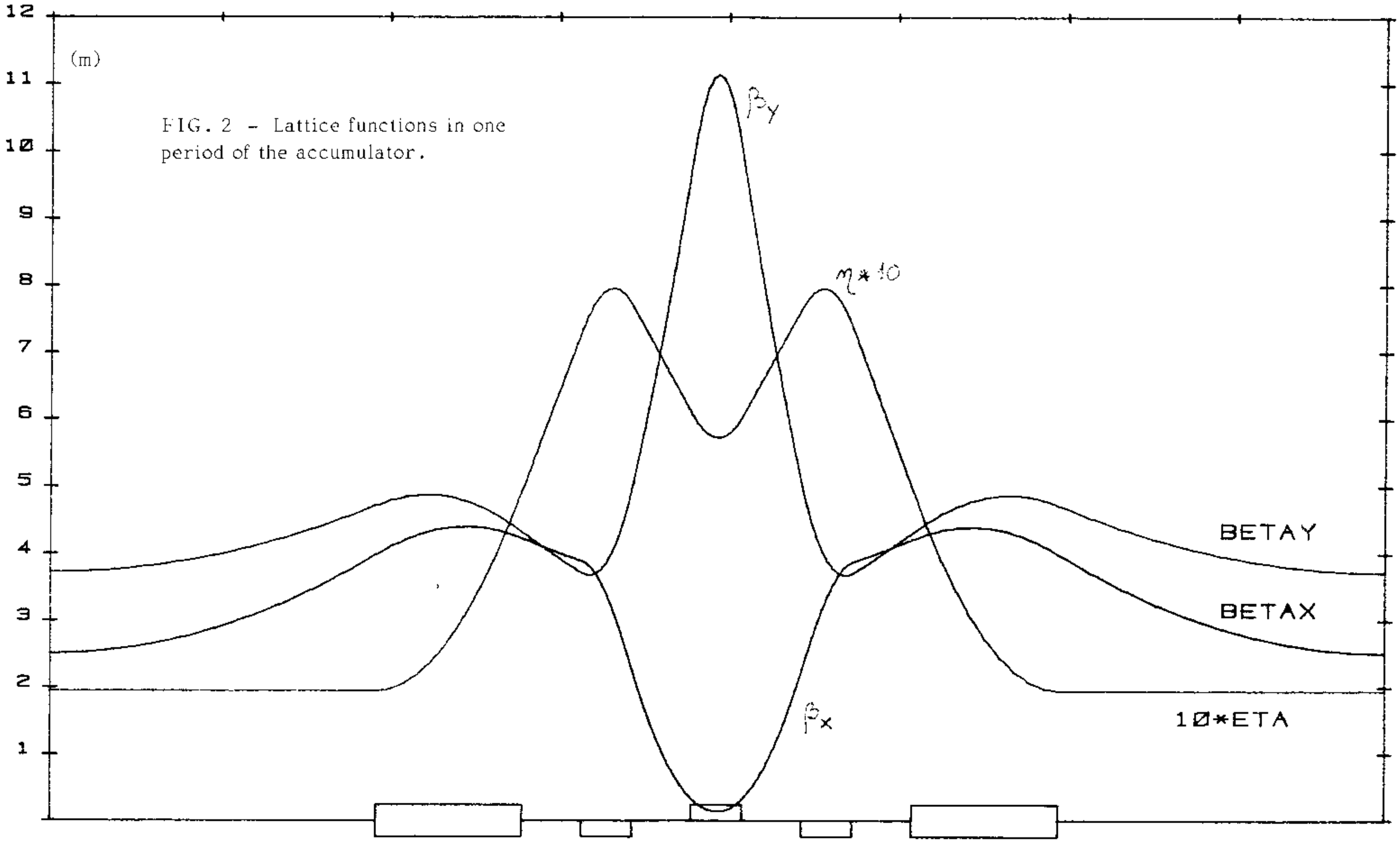

FIG. 2 - Lattice functions in one period of the accumulator.

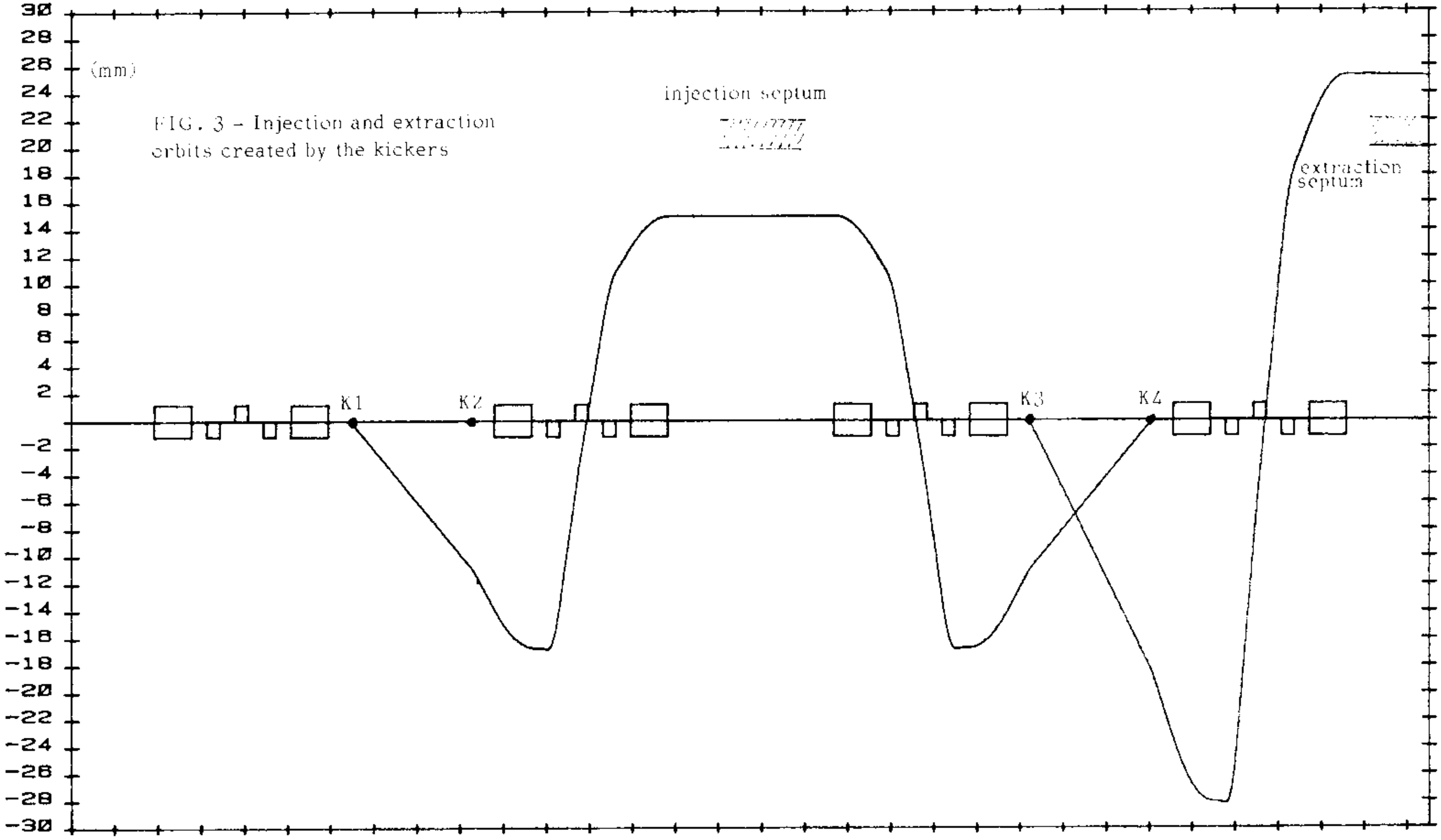

FIG. 3 – Injection and extraction orbits created by the kickers