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MAIN RING CAPABILITY AS STORAGE RING

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Introduction

The largest intensity so far accelerated in the main ring is of $1x10^{13}$ ppp. This quantity is only a factor five below the design intensity. It has been achieved with two good turns out of four turns injected in the booster and with 60% loss in the longitudinal space, equivalent to an overall loss of about 80%. With multiturn injection in the booster there is also a 30% loss in the main ring, the cause of which is not fully clear. The cure of this loss and of the losses in the injector would allow a final intensity of about $7x10^{13}$ (!).

There is hope that, with the help of the debuncher, recently installed, and of the addition of a few more cavities and/or modifications of the cavities themselves, the 60% loss in the longitudinal space could be eliminated. This should allow more current, likely $2.5x10^{13}$ ppp. On the other hand, it seems rather difficult, at the present, to get the full four turns injected because of the horizontal aperture limitation in the booster. Also, in the case we can succeed to inject four good turns, the main ring probably would not be capable of capturing all of them.

Thus we are interested in a more expeditious, alternative way to get the factor 2 in intensity that is missing. For instance, injection of negative ions in the booster has been suggested.

We propose here, as a complementary way, the RF stacking (á la ISR) of two full turns in the main ring. The idea came to us after an observation made some time ago by R. Stiening. He has indications that the beam can be stably placed at any location inside the available horizontal aperture provided that the amplitude of the betatron oscillations is not too large. Also the total available horizontal aperture is ~50π mm-mrad, which can be effectively occupied by one beam, but a "wall" seems to be present around the beam with a "local" aperture of no more than ~5π mm-mrad. This excludes an efficient capture of a beam which is obtained with four full turns injected in the booster. On the other hand, it shows that the RF stacking is possible, because this process discriminates on momenta and not on amplitudes of the betatron oscillations.

Assumptions and Requirements

In this paper we describe the RF stacking of two full turns in the main ring of a beam which is obtained with a single turn in the booster. It will be clear later on that this is the maximum number of turns that can be stacked, if the beam has to be injected at the same location as it is now with unchanged β-values and dispersion factor (X_p). Injection at lower β-values would make possible the stack of two turns with an emittance twice as big (no more! Remember, the main ring would not take it.), and the design intensity, then, could be achieved. Conversely, if injection occurs at higher X_p more turns can be stacked, though there is the limitation of the number of turns, because of the momentum acceptance of the ring and the dilution of the stack, to 6 if the RF is is turned off abruptly at the end of each stacking cycle, and, probably, to 16 if the RF is turned off slowly enough.

For two-turn RF stacking, the booster should deliver 24 consecutive pulses. This is possible only with some major hardware modifications in the booster itself.

The debuncher will soon be operating and the RF system will be modified to supply more RF power to accelerate the beam.

The combined effect of these modifications is (a) to eliminate the 60% loss in the longitudinal space, and (b) to cut down the longitudinal phase space area to 0.02 eV-s per bunch.

With a single turn injection in the booster, both vertical and horizontal emittances at 8 GeV in the main ring are close to 1.0 mm-mrad.

The momentum spread out of the booster is assumed to be

$$\Delta p/p = \pm\ 0.6\text{x}10^{-3}\ .$$

At the location of the injection kicker it is

$$X_p = 2.1\ \text{m},\qquad \beta_x = 60\ \text{m},\qquad \beta_y = 90\ \text{m}$$

which means the beam is round with 19 mm diameter.

The momentum aperture is about 1%. But the range of momentum over which the tunes can be made constant is likely only 0.7%. We may consider that in the future it is possible with a new set of sextupoles to flatten the dependence of the tunes with the momentum across the full momentum aperture.

Two-Turn Injection in the Main Ring

Let us choose to displace the beam during RF stacking from the inside to the outside of the ring, which corresponds to acceleration of the beam. Thus, as it is shown in Fig. 1, each turn is injected vertically and at the inside of the main ring by means of a new vertical kicker. This is shown, schematically, in Fig. 2. The field is applied only to the inside of the reference equilibrium orbit, which is supposed to go through the axis of the vacuum chamber. To shield the outside region, when occupied by the first turn, from the field which is kicking the second turn in, a shutter having the same length of the magnet has to be pushed down. The thickness of the shutter can be 1-2 mm. Other parameters of the kicker magnet are

length	2.0 m
magnetic field	0.1 kgauss
bending angle	0.7 mrad
bending radius	3,000 m
sagitta	0.2 mm

The dimensions are roughly about those shown in Fig. 2.

The injection will proceed in this way. (a) The shutter is up. The first series of 12 booster batches is injected on the parking orbit to the inside of the ring. (b) The shutter is still up. The beam is RF displaced to the outside, between the 12th and 13th batch. (c) The shutter is closed before the 13th batch is ready to come in. Then the second series of 12 batches is injected on the parking orbit. (d) The shutter is lifted up and the second turn is also displaced and stacked on top of the previous one.

At the end of the cycle the total beam is captured by the RF, displaced back to the central equilibrium orbit and then's accelerated.

Since to inject one full turn takes about 0.8 sec, and to efficiently capture the stacked beam another 0.1 sec, the total length of the front porch is now 1.7 sec. The lifetime in the main ring of the beam injected in the booster with the single turn mode is about 5 sec.

Finally, as it is also seen in Fig. 2, the stacking orbit and parking orbit are about 2.1 cm apart at the location of the kicker and symmetrically placed around the central equilibrium orbit. Correcting dipoles may be needed to make sure the closed orbit goes right through the shutter.

RF Stacking

Each of the two pulses must be displaced in momentum by $\Delta p/p = 1\%$, which, at the location of the kicker, corresponds to a total $\Delta x = 2.1$ cm. At high X_p (~6 m) the total displacement in length is, then, $\Delta x = 6$ cm.

During the stacking the magnetic field has to be held constant at the value corresponding to the energy of 8 GeV and to the radius of the parking orbit. The RF frequency must also be kept constant during the injection of any of the two turns.

To displace one turn from the parking orbit to the stacking orbit the RF frequency swing needed is

$$\Delta f = f\left(\frac{1}{\gamma^2} - \frac{1}{\gamma_T^{\,2}}\right)\frac{\Delta p}{p}$$

since $f = 53$ MHz, $\gamma \sim 10$ and $\gamma_T \sim 18$, it is

$$\Delta f = 5 \text{ kHz}$$

and the corresponding increase in energy, obviously is $\Delta E = 90$ MeV.

Introducing a factor 2 of dilution, the area of a single bunch at 8 GeV is 0.04 eV-s. With a safety factor of 25% the area of the moving bucket to displace the bunches should be 0.05 eV-s. By taking a synchronous phase angle of 32°, which corresponds to a ratio of 0.54 between the energy gain per turn and peak voltage per turn, the total peak voltage per turn results to be of about 100 kV. Thus the use of only one of the actual RF cavities is sufficient for the stacking cycle. The energy gain per turn is 50 keV/turn and the total displacement will take approximately 1800 revolutions, equivalent to 36 msec. This time is short enough to complete the displacement of the first turn between the 12th and the 13th booster batch and to close the shutter before the 13th batch is injected.

Before the displacement is initiated, the bucket has an area of 0.17 eV-s and a height of $\Delta p/p = \pm\ 0.8 \times 10^{-3}$, so adequate enough for a full capture of the bunches.

We may assume that the momemtum spread of each turn stacked is the height of the moving bucket, and that is $\Delta p/p = \pm\ 4.3 \times 10^{-4}$, which at the location of the kicker corresponds to a radial extension of about 2 mm. After two turns, taking into account a factor 2 for dilution, the total momentum spread is $\Delta p/p = 3.5 \times 10^{-3}$. Also, we can see that the maximum number n of turns can be, in principle, stacked in the MR is given by equating the stack momentum spread to the momentum acceptance of the ring, namely

$$2 \times (2 \times 4.3 \times 10^{-4}) \times n = 10^{-2}$$

which gives $n \sim 6$.

If the RF is turned off "adiabatically" the number n of turns that can be stacked, of course, is larger and obtained by equating the MR phase-space acceptance to the stack phase-space area. The MR phase-space acceptance corresponding to the momentum aperture of 1% is of 1.6 eV-s, thus if the beam phase space area equals the area of the moving bucket, we have

$$\eta \times 1.6 = n \times 0.05$$

where η is the stacking efficiency. With $\eta = 0.5$, we obtain $n = 16$.

In this case, nevertheless, it is required to inject the beam at large X_p.

The RF programmes (voltage and frequency) are shown in Fig. 3.

Finally, the minimum peak voltage per turn to capture the stack is 1.4 MV/turn which makes a stationary bucket with an area just equal to the beam area.

Conclusion

We give in the following three major reasons why to try RF stacking in the main ring.

(i) It would make us acquainted with a technique which will be indispensible to us for our future projects (storage rings for protons). Mainly we can learn something about the injection kicker - shutter combination and how to manipulate the beam with RF during a stacking process.

(ii) If we decide not to change the present lattice of the main ring, the RF stacking alone would not improve the intensity (although, to get 10^{13} ppp we could operate the booster in single turn injection mode and avoid a loss of particles by a factor 2. This would result in a more efficient way to use protons and a cut down of the radiation level in the booster injection area). To get higher intensity we need other methods like, for instance, the injection of negative ions. In this case, the RF stacking in the main ring would be complementary, for instance, we might halve the filling time of ions in the booster.

(iii) If we allow some change in the lattice of the main ring (essentially in the injection area), as we said at the beginning of this paper, namely either a low-β injection and/or a high-dispersion injection, we can achieve the design intensity and even more by only performing RF stacking in the main ring.

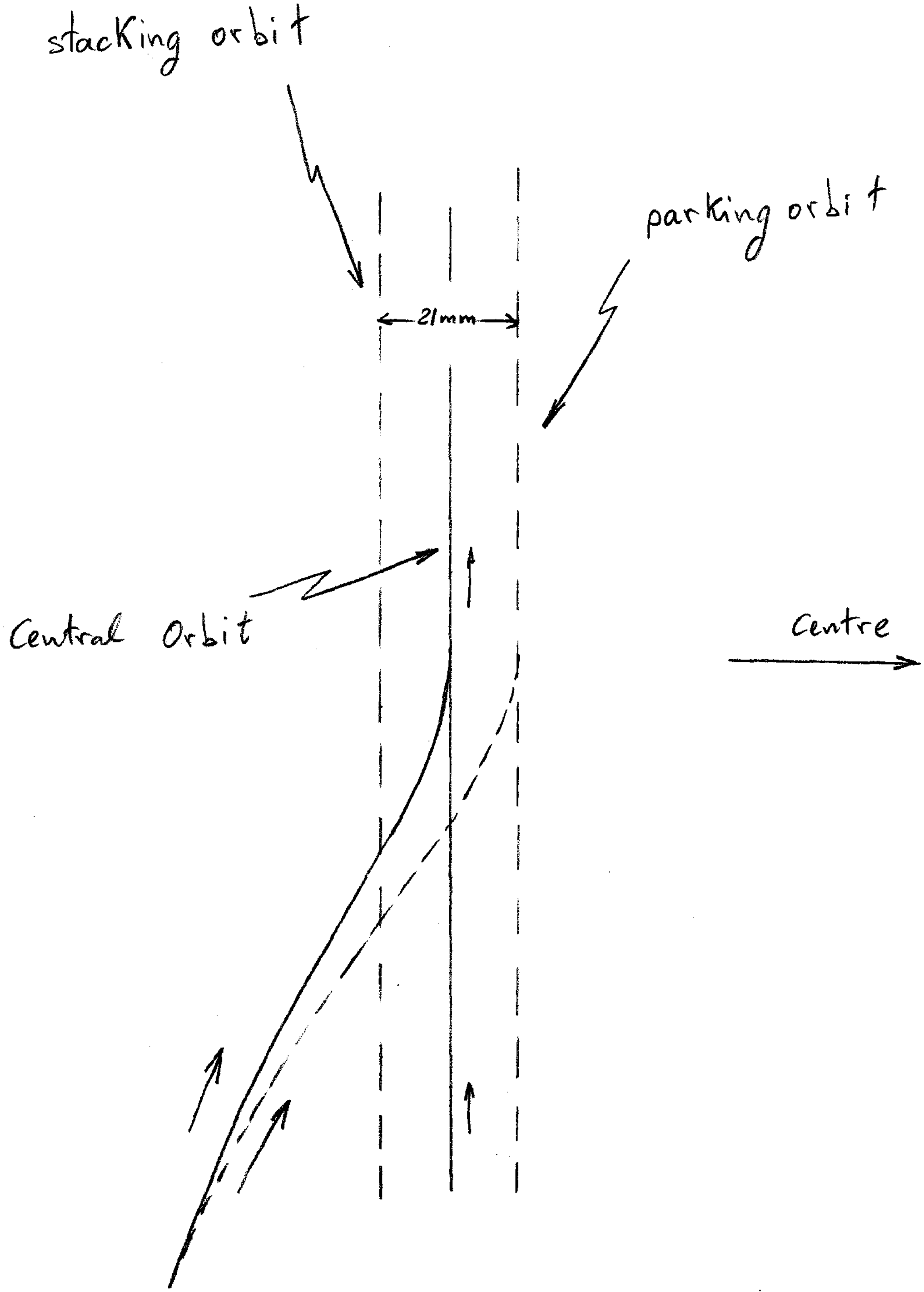

Fig. 1

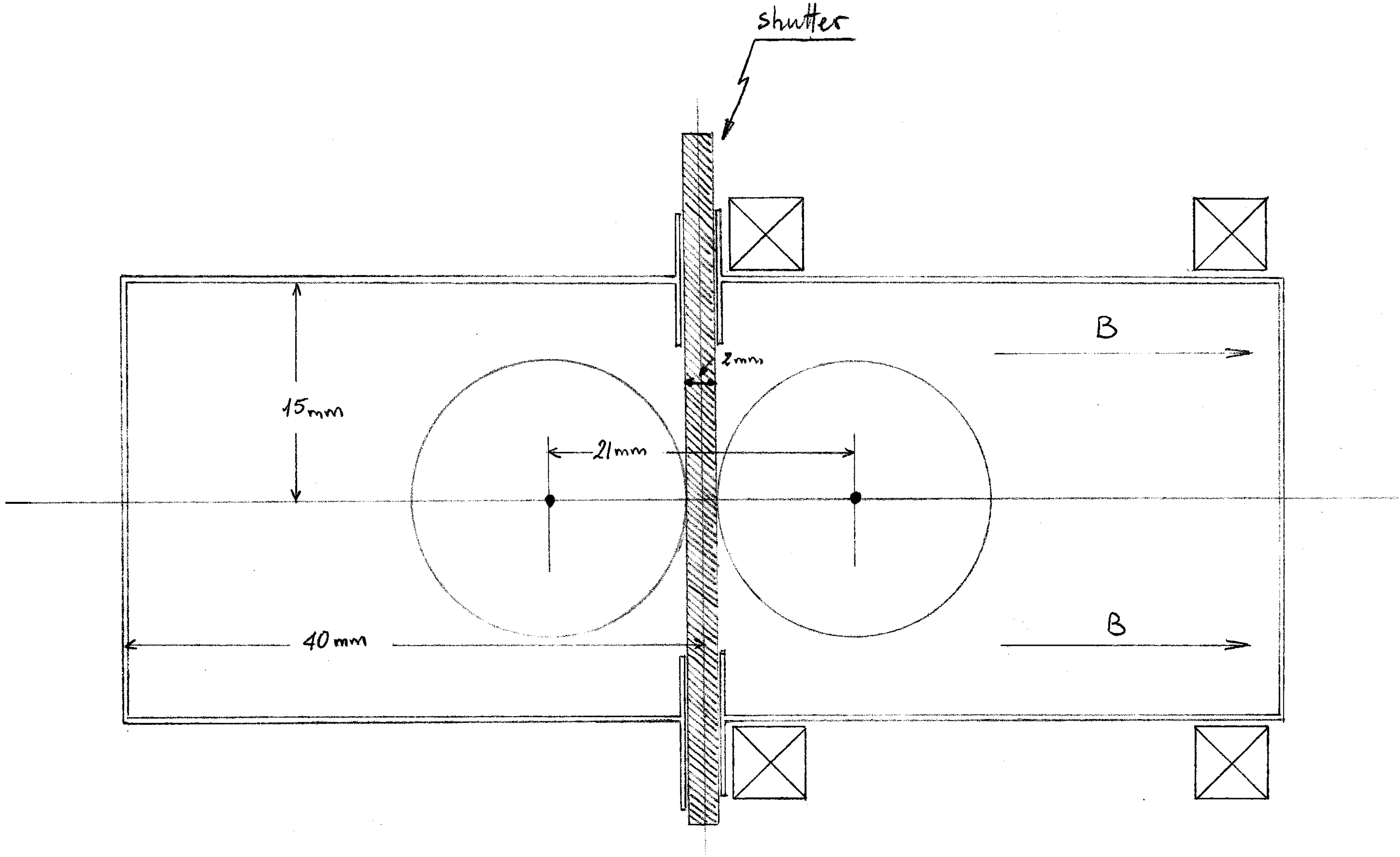

Fig. 2

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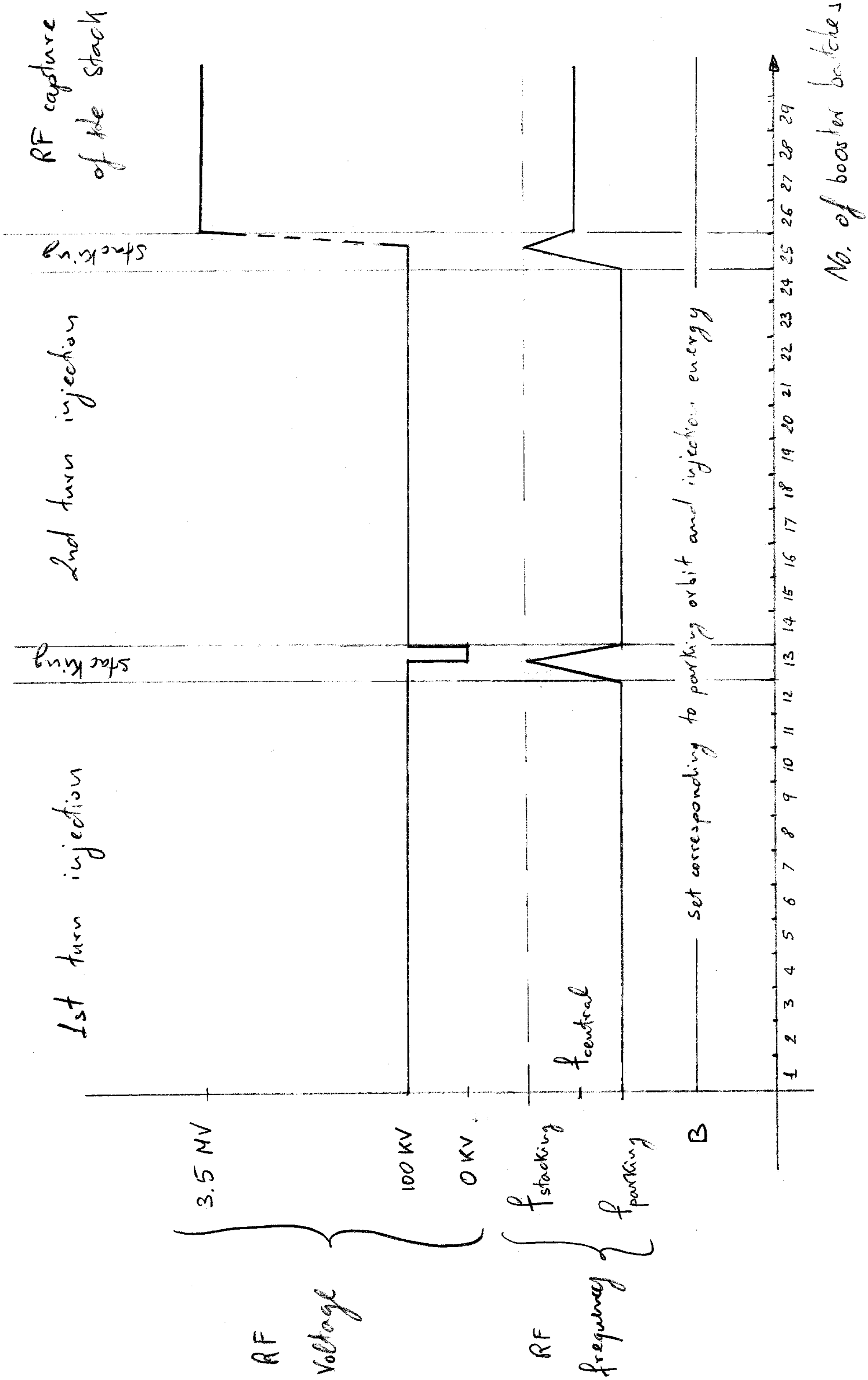
RF capture of the stack
stacking
2nd turn injection
stacking
1st turn injection
f central
3.5 MV
100 KV
0 KV
f stacking
f parking
B
RF Voltage
RF frequency
Set corresponding to parking orbit and injection energy
No. of booster batches
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

Fig.3