# A Method of Combining Bunches Using a By-pass System for a Storage Ring

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*Abstract*

By-pass system of storage rings have been proposed for accommodating special insertion devices [1] where the recovered beam can be cooled again in the ring. Here, we suggest to combine many bunches circulating in a storage ring into a single bunch or into several bunches, by switching the beam into and out of a by-pass line. The difference in length between the by-pass line and the by-passed storage ring section is an integral number times the bunch spacing. For this method fast kickers in the ring are required. An example of this method is presented in this paper.

## 1 INTRODUCTION

In electron storage rings, the number of beam bunches is very often equal to the harmonic number of the RF system, except for those cases where selective injection or single bunch injection has been used. Manipulating with the number of bunches is often needed for different reasons. One possible reason is to get single bunch operation. Another reason may be to increase the single bunch current if the injector of the storage ring is not suitable for single bunch injection, such as the case in [2]. In general it may be required to produce radiation pulses with a selected periodicity for specific synchrotron radiation use. In some cases, it is needed for improving the beam stability [3]. For manipulating with the number of bunches several ways have been used. An easy way is the "knock-out" method which unfortunately results in a serious loss of beam current. Other ways make use of multiple RF systems or of a special booster [2, 3]. Here we suggest a method to combine bunches using a by-pass system for a storage ring. This permits high bunch currents to be achieved. In order to realize this easily, a bunch extraction method utilizing coherent transverse betatron oscillations with small kicks has been investigated. In this paper we give a specific example. The conditions and the procedure of bunch combination and the movement of bunches to be combined in the transverse phase space will be described in detail. A feasible scheme of fast small kicks with low cost will be presented.

## 2 BASIC PRINCIPLE

The realization of combining beam bunches with this method relies on the path length difference for two bunches to be combined and on synchrotron radiation damping. Suppose that in a storage ring there is a by-pass line of length $L_{by}$ and a by-passed section of length $L_{ps}$. A fast extraction system connected to the storage ring on one side of the by-pass line and a fast injection system connected to the ring on the other side are requiered. For combining the beam bunches without particles loss three conditions need to be fulfilled:

- The difference in length between the by-pass line and the by-passed storage ring section is about equal to the separation between the two bunches to be combined. The separation normally is

$$\Delta L = nL/h, \tag{1}$$

  where $n$ is an integer, $L$ the circumference of the ring and $h$ the harmonic number. The corresponding time difference is $\Delta t = c/\Delta L$, where $c$ is the speed of the circulating particles.

- The timing for extraction and re-injection kicker must be such that a certain bunch can be ejected and be combined with a circulating bunch.

- During the combination process the beam bunches need to be held within the effective machine aperture. For the transverse apertures this is mainly determined by the ejection and re-injection system. For the longitudinal direction the combination is automatically satisfied with condition one.

At a certain time the extraction system ejects a bunch (or several bunches) into the by-pass line but leaves the remaining bunches undisturbed (or slightly disturbed). After the time $L_{by}/c$, the bunch going into the by-pass line is re-injected into the storage ring and stacked together in transverse phase space with an other bunch (which was behind it for $L_{by} > L_{ps}$ or was in front of it for $L_{by} < L_{ps}$). Afterwards these two bunches will merge through radiation damping. Then a new bunch combining process can be started. In this way, all of the bunches circulating in the storage ring can be combined into several bunches or into a single bunch.

## 3 EXAMPLE

For the EUTERPE ring a by-pass line has been suggested to be used for long insertion devices[4]. Here we consider that it can also be used for the combination of bunches and the adjustment of the separation between radiation pulses.

### 3.1 Combining bunches and manipulating bunch separation

The EUTERPE storage ring has a circumference of 40 m and a 45 MHz RF system [5]. Its injector is a 75 MeV racetrack microtron which is injected from a 10 MeV medical linac. Normally the number of bunches in the ring is 6. The bunch spacing or separation in longitudinal direction is 40/6 m or 133/6 ns.

Using the method mentioned above, fig.1 shows how two bunches combine. As a time step $\Delta t = T_0/h$ is taken ($T_0$ is the revolution period of particles in the ring). The length difference between the by-pass line and the by-passed storage ring section is 40/6 m.

With suitable manipulation the bunch spacing can be increased by two or six times the original spacing. Then synchrotron radiation pulses are produced with a corresponding time interval.

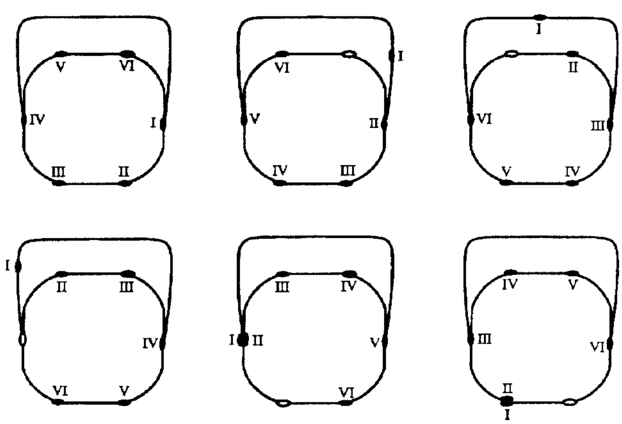


Figure 1: *Combining two bunches.*

### 3.2 Extraction and injection method

In order to realize the combination of bunches with the by-pass line, we consider to use an unusual particle extraction method. It is based on the excitation of a small coherent transverse betatron oscillation for a single bunch, using a small amplitude fast kicker.

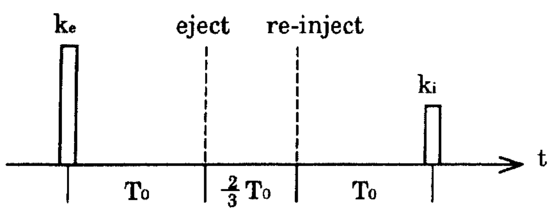


Figure 2: *Timing sequence.*

For EUTERPE the ejection and re-injection septa are placed diametrically opposite to each other, with their respective kickers $K_e$ and $K_i$ virtually on the same septum positions. The tune is adjusted to near n+1/4. The kick action only effects a single bunch. Fig.2 shows the timing sequence.

In fig.3 and fig.4, the evolution of two bunches I and II is shown in horizontal phase space at the ejection and the re-injection position. Here the numbers 0, 1, 2, 3$\cdots$ refer to the revolution numbers w.r.t. the start of the sequence. From 0 to 1 an extraction kick of 0.4 mrad is induced. After one revolution bunch I gets extracted and injected again (see number 2 in figs.3-4). Then, after another one revolution time the re-injection kicker provides a 0.2 mrad kick to bunchs I and II, by which both bunches stay within the aperture of the machine and get merged via radiation damping.

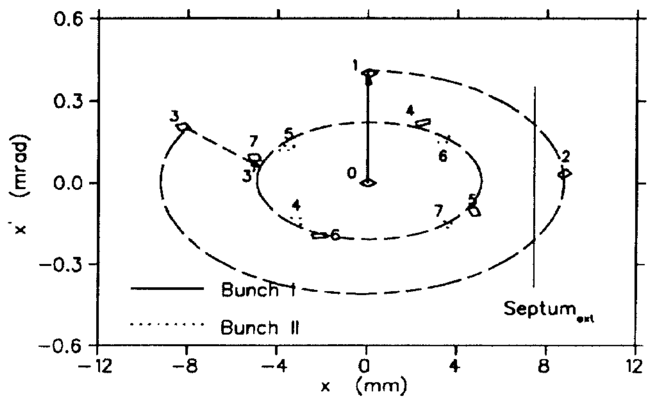


Figure 3: *Evolution of bunch I and bunch II at the* **extraction** *septum position.*

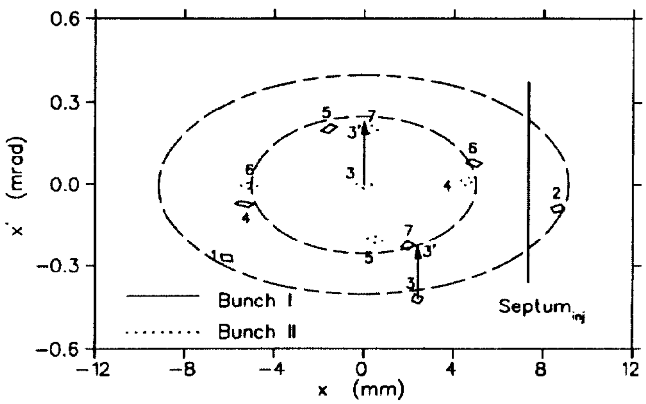


Figure 4: *Evolution of bunch I and bunch II at the* **injection** *septum position.*

In order to extract bunch I, one can also use small kicks repeatedly with a time step of m$T_0$ (m is a suitable integer) rather than one single kick. The numerical calculation indicates that taking the $K_e$ of 0.1 mrad and the time step of 4$T_0$ bunch I can be extracted into the by-pass line after 13 revolutions.

Based on reference [6], an initial analysis indicates that during the bunch combination process the EUTERPE ring is not sensible to the fourth order resonances excited by guide field errors.

It is has been checked that the aperture due to the septa has no obvious influence on the beam lifetime.

### 3.3 *Feasibility of technology with a fast small kicker*

Here we discuss an idea for a low-cost high voltage kicker system to provide a 0.4 mrad kick. It can be realized with a kicker length of 20 cm and a high voltage $U_b$ of 20 kV over a gap $d$ of 2.5 cm. Further there are two fast transistor-switches with the same capacitance $C_1$ and $C_2$ ($\approx$18 pF), see fig.5.

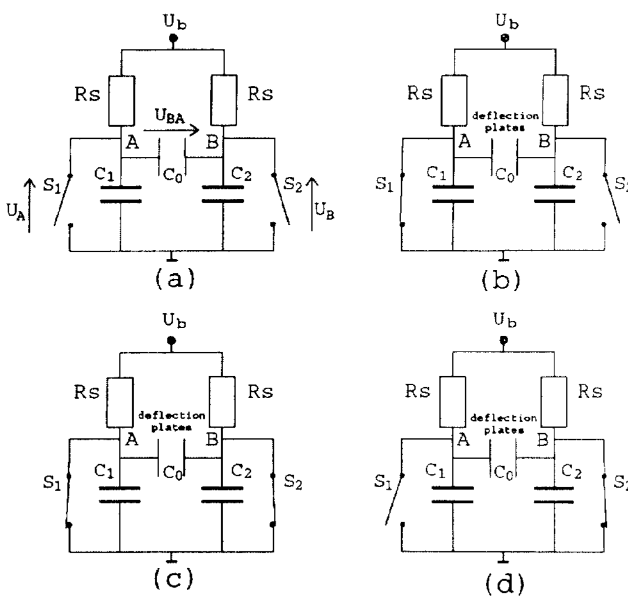


Figure 5: *Scheme of high voltage kicker system.*

The operation is as follows: at time $t_0$ the capacitors $C_1$ and $C_2$ are charged to the same voltage $U_b$ ($\approx$ 20 kV). So we don't have a field between the plates of the kicker with capacitance $C_0$ ($\approx$ 2 pF). At a certain time $t_1$, transistor-switch $S_1$ is closed and capacitor $C_1$ is discharged in a very small time-interval (< 15 ns), see fig.6.

A part of the charge of $C_2$ flows in $C_0$. The potential difference ($U_{BA}$) over the deflectionplates $C_0$ at the end of this process is $U_b \cdot C_2/(C_2 + C_0)$, and the electrical field will be $U_b \cdot C_2/[(C_2 + C_0)d]$. At the time $t_1 + \Delta t$ ($\Delta t \approx$20 ns) switch $S_2$ is closed and so the capacitors $C_0$ and $C_2$ are discharged. Now the field is zero again. A fixed time-interval ($\approx$100 ns) after $t_1$ respectively $t + \Delta t_1$, $S_1$ and $S_2$ open and the capacitors $C_1$ and $C_2$ are slowly recharged with a time constant of $R_1C_1 = R_2C_2 = \tau$ ($\approx$ 20 $\mu s$). So the potential diference $U_{BA}$ between the deflectionplates stays very small, the maximum of the absolute value of $U_{BA}$ during recharge is

$$| U_{BA} |_{max} < | \frac{\Delta t}{\tau} U_b | . \qquad (2)$$

After 5 $\tau$ the system is ready for the next kick.

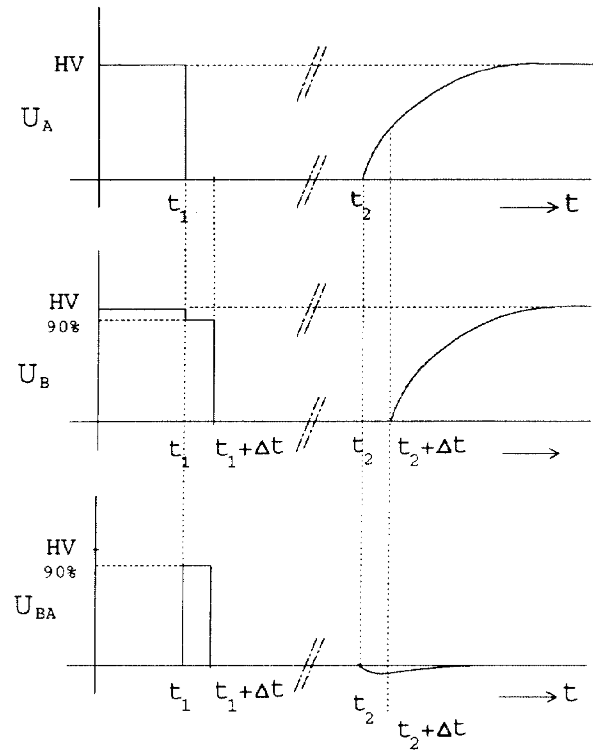


Figure 6: *Timing diagram of the kicker system.*

## 4 CONCLUSION

A method of bunch combination with a bypass line for a storage ring has been given. The technical feasibility of the required kicker performance is discussed.

## 5 REFERENCES


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