A CONTINUOUS INJECTOR-EJECTOR SCHEME FOR DAMPING RINGS

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Abstract

In this paper we describe a new injection-ejection scheme for damping rings, in which several bunches are simultaneously stored and cooled. The application of kickers becomes difficult when the injection and ejection frequency exceeds several hundred Hz. It is proposed to use several cavities in a deflecting mode at different frequencies in order to select a single pulse out of the stored pulse train.

Introduction

Recirculating linacs like ELISA[1] and CEBAF[2] are, at least in the first stage, fixed target electron machines for nuclear physics. The quality of the the electron beam in such machines will be excellent. A cooling device is not necessary. In a second stage it might be of interest to accelerate positrons as well as electrons in both fixed target and collider experiments. The electron beam will be used for the production of positrons. The beam emittance of the positrons must be improved by a damping ring.

The optimum operating energy for a damping ring will be between 1 and 2 GeV[3] and the damping time will be in the order of several milliseconds. Several bunches in different damping conditions will circulate in the ring at the same time.

In ELISA, e.g., the injection rate into the damping ring will be 12 kHz. The injection frequency for CEBAF could be even higher. Kickers to operate at such high repetition rates do not exist at present. In order to handle such high injection and ejection rates, it is proposed in this paper to use rf cavities in a deflecting mode to separate the remaining bunches from the one being ejected. The selection is done by cavities operating at slightly different resonant frequencies in such a way that the kicks of the different cavities add up only for one bunch but compensate each other partly or totally for the other bunches.

The authors were stimulated to make the present proposal by the idea of the CEBAF rf separator,[2] which is based on the CERN rf separator.[3] New is the idea to use several rf separators operating at slightly different frequencies in order to separate individual bunches one from another.

The Elements of the Injector-Ejector System

Figure 1 shows the basic concept of an rf separator which separates one bunch out of three. The separating field strength can be in the order of MV/m. As already mentioned, the optimum energy of the damping ring will be in the order of 1 to 2 GeV.[3] The strength of the kick can be in the order of mrad. This gives a rough estimate of the order of magnitude of the discussed effects.

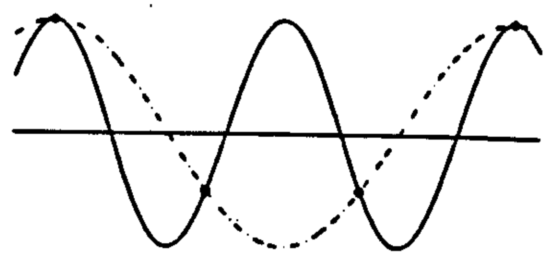

Figure 1: Separation of 1 bunch out of 3 by a deflecting cavity. The fundamental and the first harmonic act in the same manner.

The separation of one bunch out of three, as shown in Fig. 1, is achieved by a frequency which is one-third of the frequency of the bunch repetition time. It is easy to show that this frequency is not the only one which can cause this effect. The second harmonic of this frequency produces the same deflection pattern (Fig. 1) and so do all harmonics of this frequency except those whose harmonic number can be divided by three. In the following this will be explained.

At the fundamental frequency the bunch is kicked at angles of 0, $2\pi/3$ and $4\pi/3$ (0, 120 and 240 degrees). At the second harmonic the angles (see Fig. 1) become 0, $4\pi/3$ and $8\pi/3$. The latter is equivalent to $2\pi/3$ so that the bunches are again kicked at 0, 120 and 240 degrees. The next harmonic would be the third harmonics. The kicks are, therefore, at 0, $6\pi/3 \equiv 2\pi$ and $12\pi/3 \equiv 4\pi$. Thus, the 3rd harmonic does not work, and neither do any harmonics which are multiples of 3. Therefore the 1st, 2nd, 4th, 5th, 7th, 8th, 10th, 11th, 13th etc. harmonics can be used to select one bunch out of 3.

In order to discuss the proposed scheme in more detail an example is given. Assume that the injection rate into the damping ring is 12 kHz. The distance between the bunches is therefore 83.3 μsec. Assume further, for the sake of simplicity, that the bunch repetition frequency of the stored beam in the damping ring is 78.732 MHz (3^8 times the injection rate). According to the above-mentioned selection scheme (1 out of 3) 8 cavities operating at different frequencies are necessary to eject one bunch every 83.3 μsec out of the stored bunch train.

The Combination of Cavities in an rf Bunch Separator

The deflecting cavities in the above-mentioned example must be tuned to frequencies which can be derived from Fig. 1. In this example the bunch repetition frequency is 78.732 MHz. The frequency which selects one bunch out of three is, therefore, 26.244 MHz or a harmonic thereof, e.g., 1.522152 GHz (58th harmonic).

The bunch repetition frequency after the separation of the first cavity is 26.244 MHz. Separating again one bunch out of 3 leads to a separation frequency of 8.748 MHz or a harmonic thereof which is not a multiple of 3. The harmonic next to the resonance frequency fulfilling this condition is obviously the 3x58 $\pm$2 harmonic. The resonance frequency of the second cavity can therefore be 17.496 MHz higher or lower than the first cavity.

Continuing this scheme, the third cavity has to operate at an even harmonic of 8.748/3 MHz = 2.916 MHz, which is not a multiple of 3. Figure 2 shows the arrangement of cavities. In order to compensate the kicks produced by the first cavities, a second set of cavities operating at the same frequencies is installed as a recombiner.

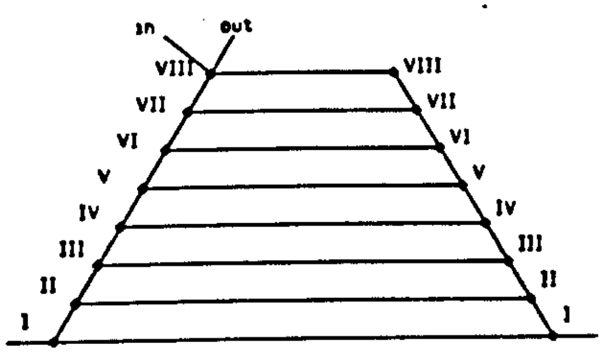

Figure 2: Schematic layout of a separator for selecting 1 bunch out of 6561 (= 3^8) bunches. Two sets of 8 cavities operating at different frequencies are used.

In Table 1 two complete examples for the selection scheme are given. The two examples are based on 1.5 GHz cavities and 500 MHz cavities respectively. The two examples show how a set of cavities must be tuned to inject and eject bunches into and out of a damping ring at a rate of 12 kHz. The bunch distance in the storage ring is 83.3 μsec.

TABLE I

Number of cavity	Example I: Frequency 1. Harm. MHz	Example I: Number of Harmonic	Example I: Resonance Frequency MHz	Example II: Number of Harmonic	Example II: Resonance Frequency MHz
I	26.244	58	1522.152	20	524.880
II	8.748	$3.(58)-2$	1504.656	$3.(20)-2$	507.384
III	2.916	$3^2.(58)-2$	1516.320	$3^2.(20)-2$	521.964
IV	0.972	$3^3.(58)-2$	1520.208	$3^3.(20)-2$	522.936
V	0.324	$3^4.(58)-2$	1521.504	$3^4.(20)-2$	524.232
VI	0.108	$3^5.(58)-2$	1521.936	$3^5.(20)-2$	524.664
VII	0.036	$3^6.(58)-2$	1522.080	$3^6.(20)-2$	524.808
VIII	0.012	$3^7.(58)-2$	1522.128	$3^7.(20)-2$	524.85

Table I also shows the limitation of this system: at lower ejection rates the frequencies get closer. At repetition rates of several hundred Hertz, however, kickers will do the job. Hence, with respect to the frequency range, kickers and rf injectors-ejectors are complementary to each other.

A More Practical Layout of the rf Bunch Separator

The rf bunch separator shown in Fig. 2 has several disadvantages and is only shown in order to demonstrate the principle. From a practical point of view such a separator is too long. The following cavity can only be installed at a position where the distance between the separated bunches is large enough so that only the selected bunch train is affected by the following cavity.

Figure 2 can be seen from a different point of view. Even when the 8 cavities act one after the other on the bunch train, each bunch is kicked by a different angle due to the different frequencies of the cavities. As a result, the kicks only add completely for the first and the 3^8th bunch when an arrangement as shown in Fig. 3 is used. The bunch separator shown in Fig. 3 is much shorter than the one shown in Fig. 2 but fulfills the same task. A set of quadrupoles providing a betatron phase advance of π must be in between the two sets of cavities. A phase jump of π converts x into $-x$ and x' into $-x'$. The phasing of the cavities in the combiner must take this inversion into account. The phase jump of π automatically makes the dispersion at the end of the combiner zero, and the whole system is dispersion matched.

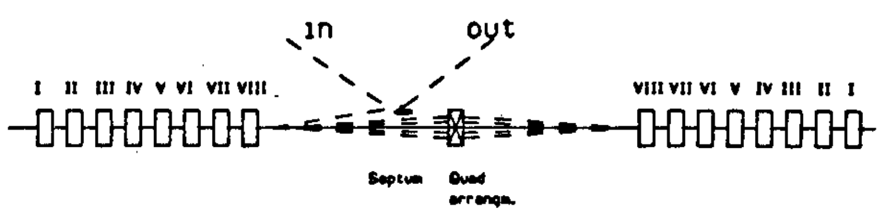

Figure 3: A bunch separator and combiner with 8 cavities in a line. The cavities are tuned to the same frequencies as before. The kicks of the individual cavities add or subtract by Fourier superposition.

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