THE DESIGN OF A SINGLE PULSE ACCELERATOR*

A. Schempp
Institut für Angewandte Physik; Universität Frankfurt am Main,
Robert-Mayer-Str. 2-4, D-6000 Frankfurt am Main 1, FRG

Abstract

For neutron time-of-flight experiments short proton beam bunches with pulse pauses of up to several µsec are needed. Such high pulse current proton accelerators can replace electron linacs of the ORELA type. The injector of such a new system will favourably be an RFQ. An RFQ-design is presented, which produces single pulses of $5\cdot10^9$ protons (1 nsec width) with repetition rates between 1 Hz and 20 MHz. Such an RFQ-scheme can also be used to produce empty buckets (beam pauses) for high current linacs injecting into synchrotrons, as discussed for the European Hadron Facility accelerator (EHF).

Introduction

Since several years interest in high current beams with a new specially shaped microstructure is increasing.

For reasons of experimental set-ups in nuclear physics of for proper injection into booster synchrotrons respectivley accumulator rings pauses between adjacent beam bunches should be between 2 and 100 buckets, e.g. 10 nsec and 1 µsec[1,2,3,4]. For high current machines like the EHF injector[5] 2/8 are planned. This means that two 400 MHz buckets are injected with a repetition rate of 50 MHz respectively 25 nsec between the microbunches. This is proposed in a straightforward way with a jump in frequency by a factor of 8 and then by forming of two 400 MHz bunches out of one 50 MHz bunch.

For neutron sources the pulse pauses must be even longer, so for a bunch to pause ratio of 1/100 a frequency jump in the normal way is not possible.

A high energy buncher for 1 MHz at 2 MeV beam energy, which should focus severalmicrobunches into one longitudinal spot, would need a voltage of approximately 7 MV and a drift length of 20 m. A main problem would be the transport of this beam to that focal point.

Buncher and chopper schemes are hard to realize for high current beams, because the second important boundary condition of these systems asks for a clean beam pause and good emittance.

This is difficult also in the EHF case, in which the reforming of two bunches gives an increase in longitudinal emittance and single particle calculations show that with space charge the adjacent buckets are not totally empty[6]. In addition the low frequency of the first stage is far from optimum, so only 15 mA can be accelerated.

In the following a scheme is presented, which can shape the pulses and pauses with help of asynchronous acceleration of RFQs. The idea uses the well known properties of the RFQ like high beam transport capability and adiabatic bunching as well as the selectivity of the fixed velocity profile to filter the proper beam microstructure.

* supported by BMFT

Basic System

An accelerator system would consist of an ion source, matching lenses and two RFQs with matching elements in between, as sketched in fig. 1.

At the end of the first RFQ the beam is bunched and has a size, which can be expressed in phase width $\Delta\phi$ of approximately $3\phi_s$ (ϕ_s synchronous phase). Beam dynamics then shows that a stable region exists (bucket fig. 2), which size depends on particle energy, frequency, accelerating field, specific charge and synchronous phase. The beam pulse now must be matched to the bucket of the second RFQ, which width is different according to the frequency change.

Asynchronous acceleration now takes the train of bunches and only those, which fit into a bucket for the new frequency, which is not a multiple of f_1, are accelerated stable. After a few accelerating cells all buckets in between will be empty. Fig. 3 illustrates this principle for a frequency ratio of 1.25 .

Fig. 4 shows single particle calculations for f_1/f_2 = 90/100 MHz resulting in a bunch repetition rate of 10 MHz. The properties of the synchronous bunch could be calculated with a normal particle code, too. The missing space charge of the neighbouring bunches has to be taken into account in this case.

In the usual design a 10 MHz preaccelerator would have to compress a bunch such that it fits into the approximately 10 times narrower one at the higher frequency.

A first attempt to get a lower bunch repetition rate ν_r for a neutron source injector would apply two RFQs with 98 and 100 MHz resonance frequencies (ν_r = 2 MHz). Unfortunately the pulse pause would not be empty, because the neighbouring bunch centers are shifted by only 3.6 per bucket. This is illustrated in fig. 5, which shows the beam current as function of time. The centers of the neighbouring bunches oscillate around the stable phase ϕ_s, which detoriates the beam. To provide a phase shift for the adjacent bunches to be outside of the separatrix the minimum frequency ratio must be $f_2/f_1 > 2\pi/(2\pi - \Delta\phi)$.

A 90/100 MHz system, as illustrated in fig. 4 gives a 10 MHz repetition rate, when a bunch width of 10 % is achieved in the first stage (ϕ_s = 10°, $\Delta\phi$ = 36°).

In a next step to reduce ν_r a 1 MHz prebuncher could be applied, but which would partly fill all buckets and would need a long drift length, which is not favourable with high current beams. Another RFQ stage is a better solution. The second stage cleans the neighbouring buckets, the third can use a small frequency ratio like 99/100 to give1 MHz for ν_r.

A higher average beam current requires higher values of ϕ_s. The problem can be solved with choice of a subharmonic for RFQ1, which increases the charge per bunch additionally. Fig. 4 shows phase widths along the RFQ system. The two adjacent 10 MHz bunches from fig. 4 now vanish.The injected proton beam at 45 MHz was 25 mA, the output beam (ν_r = 5 MHz) is I_{av} = 2.2 mA at 1 MeV.

Realisation of such a system suggests transition energies as low as possible to minimize power losses in the structures. Frequency tuning of RFQ1, which is possible in a wide range using the four-rod-RFQ structure[7] allows a change of the repetition rate. Beam losses in the structure have shown no influence on sparking as long as a good cooling of the electrodes can be preserved, which has been tested with the four-rod-structure, too.

Because only the ratio of frequency detuning determines the repetition rate ν_r, results are valid for applications for 200, 400, 800 and 1200 MHz, too. Even for electron beams in high gradient structures or wake field accelerators asynchronous acceleration can be used to isolate single bunches.

Applications

The starting point was the search for a design giving a 1 nsec pulse with 1 µsec pause (1 MHz repetition rate ν_r), as would be necessary for a neutron source injector[1,3].

The 45/100 MHz system as a starting point, the bunch repetition rate ν_r has to be further reduced. The logical solution is another frequnecy transition: 45/99/100 MHz would give a clean ν = 1 MHz. Fig. 7 shows the longitudinal output emittance for an injected beam of 25 mA at 20 keV and an output beam of I = 1.1 mA. This was achieved by adding other prebuncher with 20 MHz in front of RFQ1.

Tuning the RFQ1 to 47.5 MHz would give a ν_r = 0.5 MHz. Now, manipulating the RF pulse of RFQ1 such that the accelerating field amplitude E_o stays smaller than $E_o \cos\phi_s$ and than a small spike of less than 1 µsec length is added with a fast regulation system, pulse repetition rates of arbitrary low frequency can be produced. The advantage of this system would be less beam losses in RFQ2. Applying a fast chopper with p. e. 1 MHz (or an asynchronous one with a higher frequency, too) the two stage system 45/100 MHz could be used as well.

References

1. F. Käppler, G. Schatz, Verhandl. der DPG 198, p. 945
2. A. Schempp, Univ. Frankfurt, Inst. f. Angew. Physik, Int. Rep. 78-4
3. A. Crametz et al., Nucl. Instr. Meth. 242 (1986) p. 179
4. D. Trong et al., Nucl. Instr. Meth. 228 (1985) p. 217
5. P. Blüm, A. Citron, Proc. 3rd EHF-Workshop Karlsruhe 1986
6. A. Schempp, Univ. Frankfurt, Inst. f. Angew. Physik, Int. Rep. 86-5
7. A. Schempp et al., Proc. 1984 Lin. Acc. Conf. Seeheim, GSI-84-11 (1984) p. 100

Table 1 150/400 MHz EHF injector (ν_r = 50 MHz)

	RFQ1	RFQ2
T_i [keV]	50	300
T_F [MeV]	0.3	2.0
f [MHz]	150	400
I_{lim} [mA]	100	200
ϕ_s [°]	70 - 30	30
cell number	50	52
length [m]	1.0	0.8
aperture [mm]	2.5	2.5
voltage [kV]	120	150
σ_o [°]	90	60

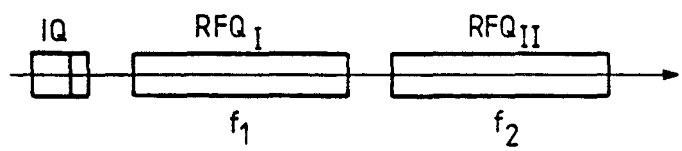

Fig. 1 RFQ system

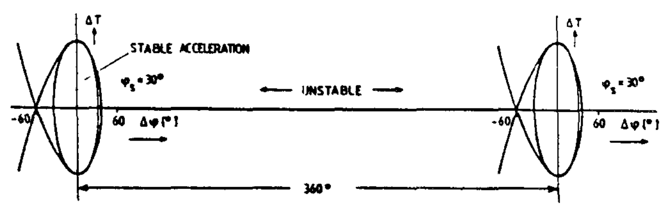

Fig. 2 Buckets for a synchronous phase of ϕ_s = 30°

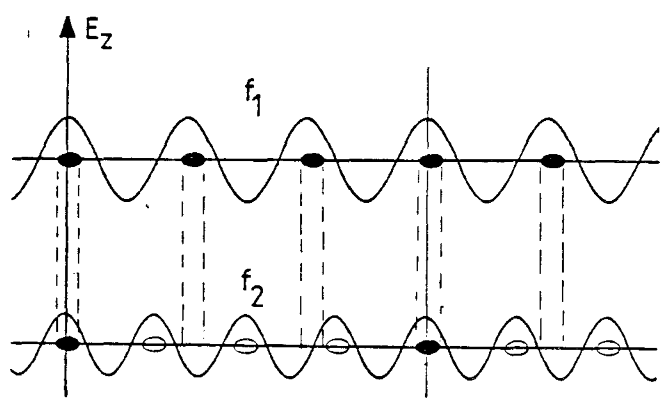

Fig. 3 Scheme of asynchronous acceleration

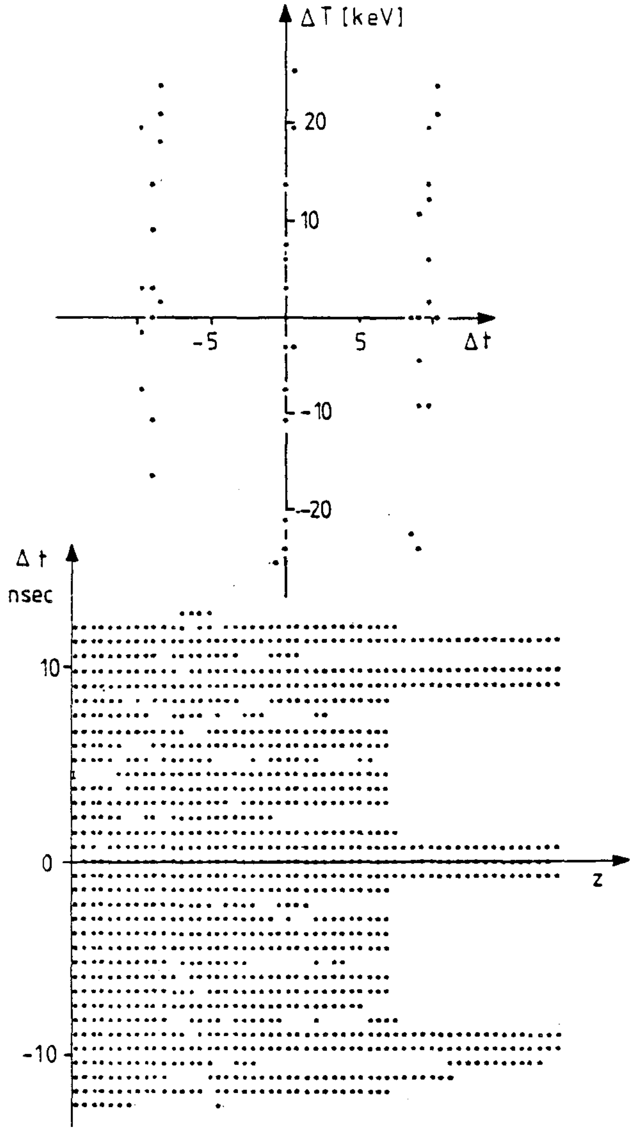

Fig. 4 Single particle calculation for f_1/f_2 = 90/100 MHz RFQ system

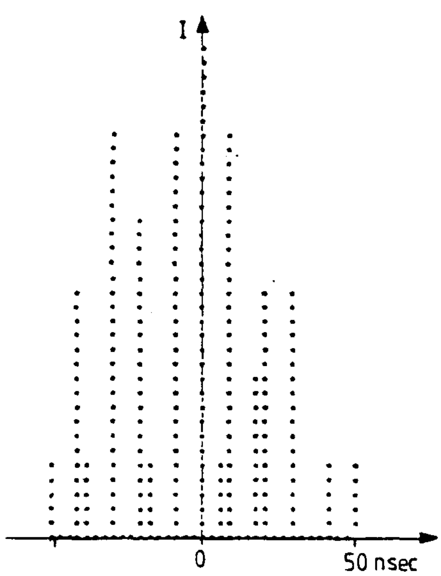

Fig. 5 Beam as function of time for a 98/100 MHz RFQ system

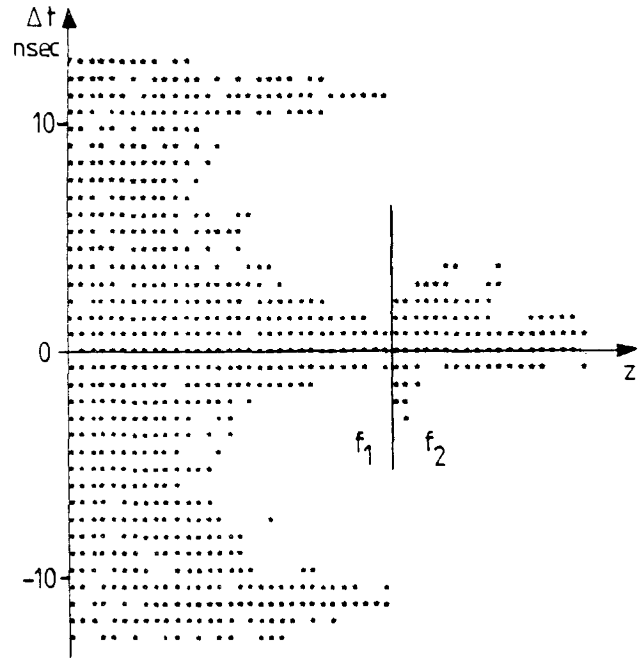

Fig. 6 Beam width along a 45/100 MHz RFQ system

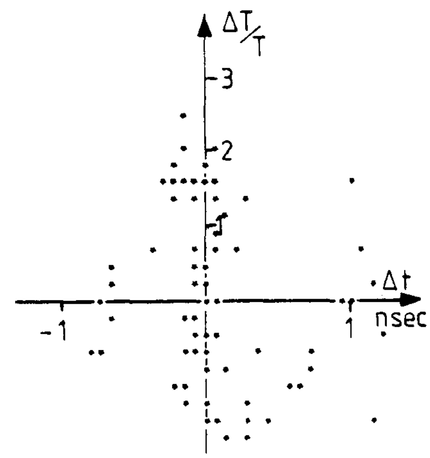

Fig. 7 Output longitudinal emittance for a 45/99/100 MHz system with average current of $\bar{I}$ = 1 mA

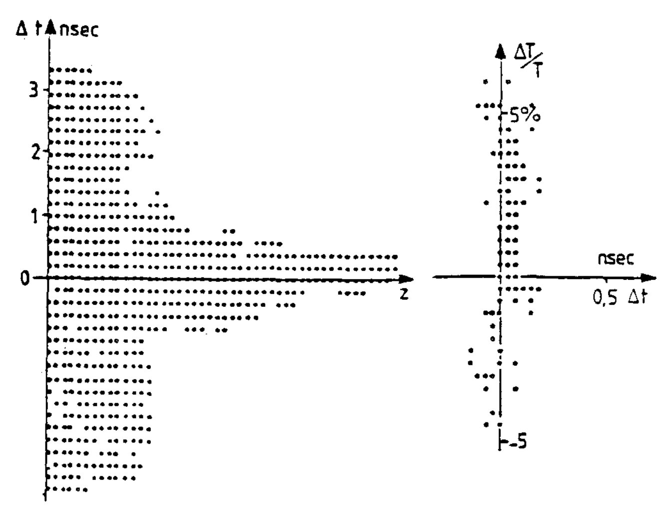

Fig. 8 Output longitudinal emittance for a 150/400 MHz RFQ system