NEW FEATURES OF THE ΔT-PROCEDURE FOR AN INTENSIVE ION LINAC

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Abstract

We investigate Δt-procedure features connected with using the longitudinal bunches instead of the single particle for the tuning of the ion linac. The Δt-procedure for longitudinal bunches is found to be correct from viewpoint of the minimal oscillationof the bunch center of gravity excluding the setting of the RF field amplitude too high. The error of the amplitude estimation is determined to be a function of the root-mean-square bunch sizes. Also we consider Δt-procedure for cavities with deviations of their parameters from design values. Some results of mutual compensation of such deviations in the linear accelerator of Moscow meson factory (MMF) are shown. We discuss briefly the nonlinear method of data handling which allows to set RF amplitude and phase as well as to find the size of the effective bunch.

Introduction

For enchancing of the efficiency of ion linear accelerator in the energy range of the order ~100 MeV the radio frequency increases by the factor 4÷5. As a result effective bunch almost entirely occupies the capture region and we have a problem with particles near separatrix. The deviation of parameters of the accelerating structure (field value in the cavity, length of tanks e.t.c.) also can lead to the particle loss. At the same time the particle loss for meson facilities with average current ~1 mA are restricted strongly by requirement of radioactive purity. From this point of view it becomes necessary to revise some aspects of the Δt-procedure, developed by K.R.Crandall for tuning of the LAMPF linac, especially as the difficulties, encountered in reaching the design parameters in the linear accelerator of LAMPF[1], point to the importance of this problem.

Also one takes into account that accelerator structures are designed for a single synchronous particle. The using of the longitudinal bunches in an accelerator should change optimum conditions of the particle motion in longitudinal phase space. Hence it is very important to investigate the phase movement of the bunch center of gravity to decrease coherent oscillations and particle loss.

ΔT-procedure

Δt-procedure is a method based on the time-of-flight measurements. It allows to set the design field amplitude (i.e. to form the capture region of the given sizes) and to put the particle into the determined phase with respect to the RF field. Let us briefly consider the scheme of Δt-procedure carried out with a single particle for Nth cavity of the "ideal" (without any deviation) accelerator[2]. Experimentally measured is the change of the flight time of the particle through Nth cavity

$$t_1 = t_1^{on} - t_1^{off} \qquad (1)$$

and through (N+1)th cavity

$$t_2 = t_2^{on} - t_2^{off} \qquad (2)$$

when a module being adjusted is turned from "off" to "on" (fig. 1). Then one substracts design values from t and t ones:

$$\Delta t_1 = t_1 - t_1^{design} \qquad (3)$$
$$\Delta t_2 = t_2 - t_2^{design}.$$

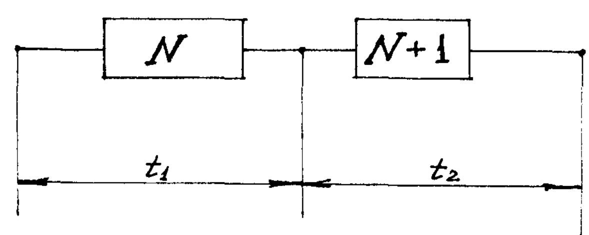

Fig.1 The scheme of the Δt-procedure.

The varying of the RF phase gives the Δt_2 vs Δt_1 curve (curve of the phase scanning). The slope of this curve changes as the RF amplitude E is varied and the design amplitude E_0 can be setted by the finding of the design slope.

Intersection point of curves of phase scanning measured at different RF amplitudes corresponds to the synchronous phase for E_0.

Now let us consider Δt-procedure for "nonideal" cavity, i.e. cavity with deviation of its accelerating structure parameters from design values.

Nonideality of the cavity.

The high-energy parts of both LAMPF and MMF consist of the tanks with identical accelerating cells. In this structure so-called quasi-synchronous particle is supposed to be design particle. Fixed input values of velocity and phase (β_{in} and φ_{in}) correspond to the quasi-synchronous particle in the design cavity. The real cavity can strongly differ by tank and drift space length, by field amplitude in cells e.t.c. from the design one.

The deviation of the various cavity parameters leads to the change of the parameters of the quasi-synchronous particle or, in other words, changes equivalent phase velocity in the cavity β_s[3]. In its turn the deviation of the value β_s from design one means the energy mismatch of the cavity and adjacent to it.

The detailed analysis shows that Δ t-procedure provides the possibility to find both the degree of cavity nonideality ($\delta\beta_s/\beta$) and deviation of input velocity from design value ($\delta\beta_{in}/\beta$) (this value defines the accuracy of the tuning of the previous cavities). It appears that the intersection point of curves of phase scanning shifts in ($\Delta t_1, \Delta t_2$) plane and has new coordinates for "nonideal" cavity[4]:

$$\Delta t_1 = A_N \cdot \frac{\delta\beta_{in}}{\beta}$$
$$\Delta t_2 = A_{N+1} \cdot \left(\frac{\delta\beta_{in}}{\beta} - \frac{\delta\beta_s}{\beta}\right)\cdot 2 \qquad (4)$$

where A_N and A_{N+1} are design constants for cavity being adjusted and next to it. Synchronous phase for arbitrary amplitude E now lies between point (4) and the point where Δt_2=0 and it divides this curve segment in proportion $(\frac{1}{2}\mathrm{tg}\,\mu)^2$, where μ is the phase advance in the cavity.

This feature of Δ t-procedure has been used for energy matching of the cavities of MMF while tuning with no beam. The energy match of the cavity and adjacent to it means that the value Δt_2 is equal to zero. The method of mutual compensation of various cavity error gives the possibility to make value Δt_2=0 by the change of the drift space between tanks in the cavity[3].

Computed curves of phase scanning for various RF amplitude are shown on fig. 2 .

Dashed lines correspond to the first cavity of high-energy part of MMF. The value Δt_2 without any correction is equal to 2.9°. Solid lines are the same curves after carrying out the required drift space correction. In this case Δt_2 is equal to $2.3^\circ \cdot 10^{-3}$. After such correction the synchronous phase for RF amplitude E_o appears to lie in the intersection point again.

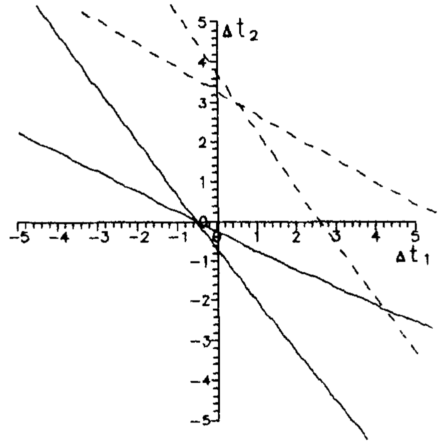

Fig.2 Curves of the phase scanning for the first cavity of MMF linac before (dashed lines) and after (solid lines) correction of "nonideality" of the cavity.

Δt-procedure for longitudinal bunches

Phase sizes of effective bunch are determined both by the single bunch sizes and by the oscillation amplitude of the centeres of the bunches. Calculations show that design instabilities of RF amplitude and phase in MMF linac almost completely compensate adiabatic compression and thus sizes of the effective bunch remain along the accelerator. The phase motion of most of the particles is extremelly nonlinear in this case. Taking into account the separatrix form one should expect the phase trajectory of bunch center to be symmetric along the velocity axis and to be shifted along the phase axis.

One can get the formula of bunch center motion by solving the equation of particle phase motion as a second approximation. Terms with doubled frequency of the longitudinal oscillations appear in the solution and the oscillation origin shifts along the phase axis by the value

$$\Delta\varphi = \frac{1}{4}\cdot\mathrm{ctg}(\varphi_s)\cdot D^2 \qquad (5)$$
$$D^2 = D_\varphi^2 + (w\cdot D_\beta/\Omega)^2$$

where D_φ and D_β are phase and velocity dispertions of particle distribution, w - the acceleration frequency, Ω - the frequency of phase oscillations, φ_s - synchronous phase (for MMF $\varphi_s = 33^\circ$).

So bunch performs oscillations around new synchronous phase shifted from design one by value (5). Phase oscillations of the longitudinal bunch (Gauss distribution with $D_\varphi = D_\beta\cdot w/\Omega$ = 0.263rad) are shown on fig.3.

Solid line corresponds to the design RF phase and the dashed one - to input phase in each cavity calculated by formula (5). One can see that oscillation amplitude becomes less in a second case.

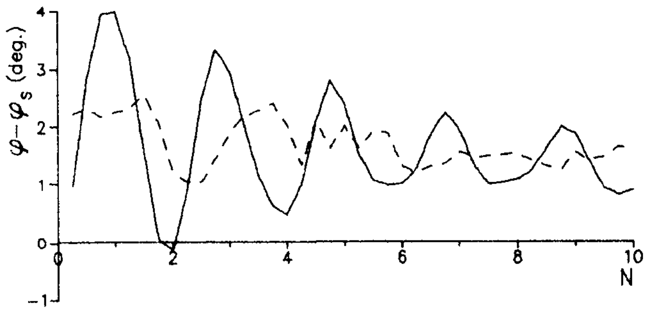

Fig.3 Phase oscillations of the bunch center vs cavity number for various input phases. Simulation has been made without instabilities of the accelerating field.

Because of shift of synchronous phase the bunch moves in the RF field with amplitude deviation

$$\frac{\Delta E}{E} = tg(\varphi_s)\cdot\Delta\varphi_s = -\frac{1}{4}\cdot D^2 \qquad (6)$$

This formula explains the tendency to underestimate the RF amplitude for longitudinal bunches, detected in Ref.2 by numerical simulation. We also have made some simulation of Δt-procedure using longitudinal bunches and it was found that amplitude estimation error is described by eq. (6). The errors in setting the field amplitude obtained by numerical simulation and by (6) as the functions of effective bunch size D are shown on fig.4.

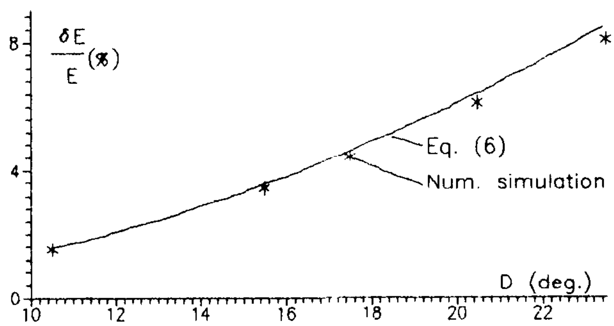

Fig.4 The value of the RF amplitude underestimation vs the root-mean-square bunch size D ($D_\varphi = D_\beta \cdot w/\Omega = D/2$).

Moreover, the phase adjusting by method developed for a single particle puts the bunch center of gravity exactly into a new synchronous phase. That is, one needs no modifications of the Δt-procedure for longitudinal bunches if we can set the RF amplitude some greater then designed. This result also has been tested for nonideal cavities ($\delta\beta_s/\beta \neq 0$) with the deviation of input velocity ($\delta\beta_{in}/\beta \neq 0$).

Thus the Δt-procedure will be correct for longitudinal bunches if it is necessary to minimize the oscillation of the bunch center of gravity. We note that the phase sizes of the bunch as well as the value of the field underestimation are unknown in this case.

Handling of the experimental data

The results above have been obtained for linear Δt-procedure, i.e. for the linear method of data handling. But its accuracy diminishes as the cavity number increases. At the same time the methods of nonlinear regression analysis allow to find the RF amplitude and phase, the input velocity deviation and even root-mean-square bunch size.

While using the nonlinear method we search the minimum of some objective function of four variables mentioned above which describes the deviation of experimental data from designed ones. It must be pointed out that description of the bunch sizes by a single parameter D is correct only for the cavities with N>10 where the bunch becomes matched (i.e. $D_\varphi = D_\beta \cdot w/\Omega = D/2$).

The main shortcoming of the nonlinear method is loss of the accuracy and growth of the time of the data handling as the number of variables increases. Therefore the simulation of the tuning process has been carried out only for matched bunches and for ideal cavities ($\delta\beta_s/\beta = 0$). The error of the bunch size estimation as function of the time-of-flight measurement error for one iteration is shown on fig.5.

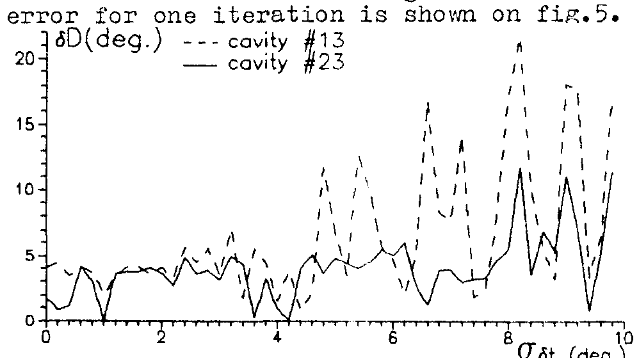

Fig.5 The error of the bunch size vs the dispertion of the normal random error of the Δt-measurements.

The using of the iterative scheme of the data handling might lead to the decrease of the estimation error. And the combination of linear and nonlinear methods possibly can lead to further improvement of the Δt-procedure as well.

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