The Δt Procedure Application at the INR Linac

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Abstract

The Δt tune-up procedure has been developed for setting phase and amplitude of the rf field in multi-tank ion linacs [1,2]. This procedure is used successfully at the INR linac. The special features of the Δt procedure as well as a computer model for our linac are discussed. The results of rf amplitude and phase settings are given.

1 INTRODUCTION

The INR linac consist of 5 Alvarez tanks at 198.2 MHz followed by 28 DAW modules at 991 MHz. In the INR linac, the first 5 DAW modules are turned on by using the Δt procedure originally described by R.Crandall and D.Swenson [1]. For higher energy modules the slope of the variable phase curves is not sensitive to the rf field change.

To set the rf field amplitude in the higher energy modules, the phase is scanned and a peak in the time-of-flight (or the beam energy) change is determined and is compared with theory [3,4].

The Δt measurements in the higher energy modules are made by using the beam harmonic monitors (BHM) operating on the third harmonic and located downstream of the module. The synchronous phase is determined by finding the intersection point of the experimental phase variable curve for the input energy ΔW_A = constant with the perpendicular to the line $\Delta\varphi_A = 0$ in the Δt-plane. Finally, for modules from 21 to 28, the aforementioned method can be used by using an extra 1-module drift for the Δt measurements.

2 COARSE METHODS TO SET RF FIELD PARAMETERS

It is necessary to set the rf parameters to within about 5° and 5%, phase and amplitude, of the optimum value before conducting the Δt procedure. The INR linac includes an intermediate energy (160 MeV) extraction switchyard with a 26° bending magnet. The magnet can be used as a spectrometer to set coarsely the rf field in the first 4 modules of the DAW structure. If the spectrometer is tuned to bend the synchronous energy of the module being adjusted then the beam current at that energy depends on a phase of the rf field (see Fig. 1). The width of the curve becomes narrower and disappears as the rf ampli-

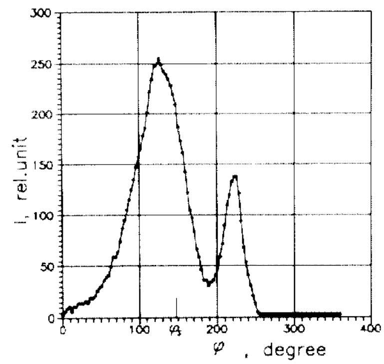

Figure 1: Spectrometer output signal vs accelerating field phase

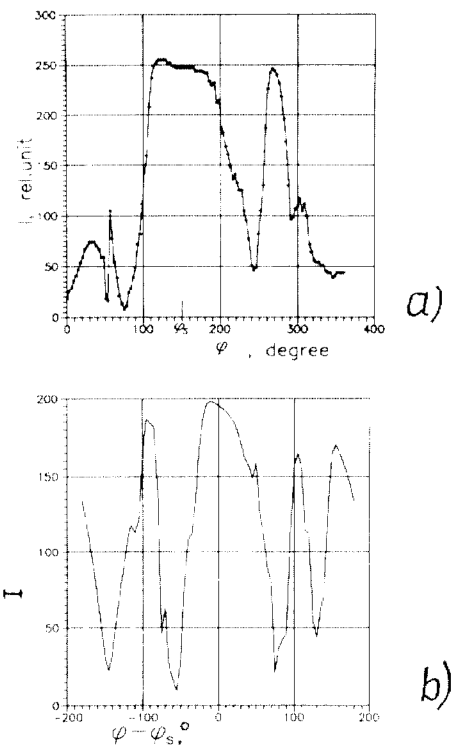

Figure 2: Experimental (a) and calculated (b) beam induced signals for module #2.

tude is decreased. As the phase is varied in the module a third harmonic signal induced by the bunched beam is measured using the BHM located downstream of 1 module. The experimental and calculated beam induced signals for module 2 are shown in the Fig. 2. The synchronous phase is determined at a calculated distance from the left edge of the phase scan curve. It turns out that the shape of these curves is retained even if the rf field level is below the cutoff value of $E_0 \cos\varphi_s$. Therefore, in order to determine the synchronous phase, two signals are analyzed: the beam harmonic signal and the beam current of the separated energy downstream of the spectrometer.

In order to set the rf parameters for modules in the energy range 160-600 MeV, the absolute value of the beam energy change is measured using a time-of-flight technique as the phase is varied. The beam energy is measured using 2 BHM placed $\sim 1m$ apart in a drift space. There is one pare of BHMs at every third module. The BHMs are calibrated off-line using a sinphase excitation. Then, the beam passing through the two detectors induces a phase difference in the measuring circuits. Since there is only a small drift space between BHMs, the precision of the absolute energy measurements is not high ($\pm 1\%$), but it is enough for our purposes. The phase difference and beam energy vs rf phase at the module #5 are shown in Fig. 3.

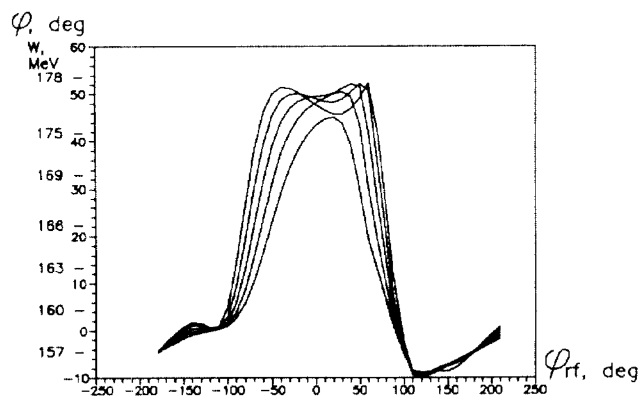

Figure 3: Phase difference and beam energy vs rf phase of module #5.

3 INFLUENCE OF COMPUTER MODEL ON ΔT RESULTS

According to our study the computer model of the beam acceleration process strongly influences the Δt design values. Two computer models which are used to generate the design Δt values have been compared: 1) one particle simulation, 2) bunch simulation (multi particle model). Let us assume that the latter corresponds to the actual beam in an accelerator .

If a one particle simulation is used to generate the design Δt-values, two independent errors arise: 1) an amplitude error from the overestimation of the rf level and 2) a phase error due to a displacement of the Δt-plane origin $(\Delta\varphi_{2p}, \Delta\varphi_{1p})$ relatively to the actual Δt-plane $(\Delta\varphi_{2b}, \Delta\varphi_{1b})$ (see Fig. 4). The origin of the

Table 1:

Module number	1	2	3	4	5
$\delta E/E, \%$	1.70	1.60	1.20	1.00	1.80
$\delta x, deg$	-1.33	-3.53	-2.80	-1.45	0.20
$\delta y, deg$	0.97	-4.48	-4.62	-0.25	0.80
$\delta\varphi_s, deg$	1.70	2.10	1.50	1.40	0.10

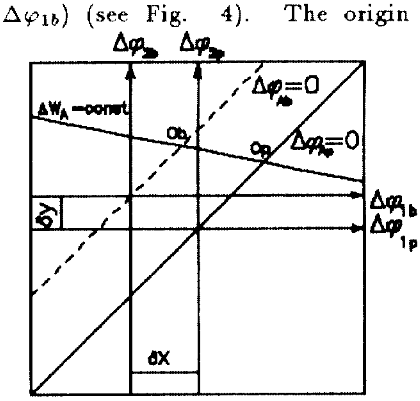

Figure 4: Displacement of Δt-plane origin.

phase error can be seen as follows. The measured curve ($\Delta W_A = constant$) is generated on the Δt-plane $(\Delta\varphi_{2p}, \Delta\varphi_{1p})$ by using the one particle simulation. The intersection point of the measured curve with the line $\Delta\varphi_{Ap}$ corresponds to the synchronous phase. However, the actual signals in the Δt-measurement circuits are induced by a bunched beam, so the curve $\Delta W_A = constant$ is displaced on the vector $\delta\vec{r} = \{\delta x, \delta y\}$ relative to the same curve shown in the coordinates of $(\Delta\varphi_{2p}, \Delta\varphi_{1p})$. This means that the Δt-plane corresponding to the actual beam is shifted relative to the calculated Δt-plane $(\Delta\varphi_{2p}, \Delta\varphi_{1p})$. Hence, the actual synchronous phase (point O_B) differs from the determined one by the value:

$$\delta\varphi_s = a_{11}\delta x + a_{12}\delta y \tag{1}$$

where a_{ij} are the elements of matrix transformation [2]:

$$\begin{bmatrix} \Delta\varphi_A \\ \Delta W_A \end{bmatrix} = (A) \begin{bmatrix} \Delta\varphi_1 \\ \Delta\varphi_2 \end{bmatrix} \tag{2}$$

$\Delta\varphi_1$, $\Delta\varphi_2$ are expressed in degrees of 594.6 MHz. The total value of the phase error is determined from the expression:

$$\delta\varphi_\Sigma = \delta\varphi_s + \delta\varphi_{sE} \tag{3}$$

where $\delta\varphi_{sE}$ is the error which arises from amplitude overestimation. The error $\delta\varphi_{sE}$ is caused by the dependence of the slope of the target line $\Delta\varphi_A = 0$ on the rf amplitude in the module. Moreover this error depends on the value of ΔW_A and is equal to zero for the synchronous input beam energy.

The data received from the comparison of the two computer models for the first 5 DAW accelerating modules of the INR linac are given in Table 1. The error values depend on the ratio of bunch sizes to bucket area as well as on the quality of the beam matching in longitudinal phase space. Therefore, it is clear that the design parameters for the Δt procedure must be generated by a multi particle simulation.

4 ΔT MEASUREMENT TECHNIQUE

A simplified block diagram of the phase meter circuit (PMC) is shown in Fig. 5. It includes amplitude detec-

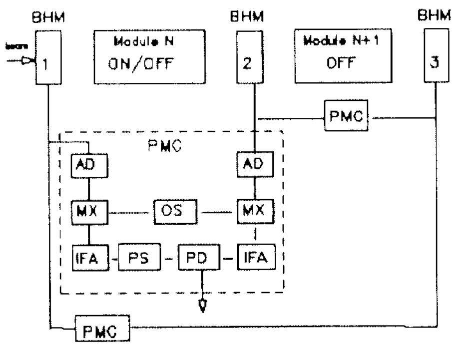

Figure 5: Simplified diagram of phase meter circuit.

tors (AD), an oscillator (OS) (f = 601.1 MHz), mixers (MX), intermediate frequency clipping amplifiers (IFA), a controllable phase shifter (PS) and a phase detector (PD). The phase shifter is a matched spiral transmission line with a sliding electric contact moveable by step motor. The phase can be varied by about 1200° (f = 594.6 MHz). The phase shifter is calibrated offline to an accuracy of a few tenth of a degree at 594.6 MHz. To eliminate intra-pulse instabilities, the output PD signal is integrated.

$\Delta\varphi_1$ and $\Delta\varphi_2$ are measured using signals from BHMs 1 and 2 and from BHMs 1 and 3 respectively. To turn off module N, the rf pulse is delayed with respect to the beam pulse. The phase difference signal from monitors 2-3 is used to verify the beam stability and is used only when the module is off.

The phase of the module rf field is varied by changing the electrical length of a mechanical phase shifter in a feedback loop of an automatic phase stabilization system. The position of the phase shifter is determined by measuring the voltage signal U_φ . $\Delta\varphi_1$ and $\Delta\varphi_2$ are measured for several points as a function of U_φ in the vicinity of the preliminary synchronous phase setting and the best straight line fits are found:

$$\Delta\varphi_1 = k_1 U_\varphi + b_1 \tag{4}$$

$$\Delta\varphi_2 = k_2 U_\varphi + b_2 \tag{5}$$

These expressions are the parametric equations of a variable phase line:

$$\Delta\varphi_2 = k\Delta\varphi_1 + b \tag{6}$$

were $k = \frac{k_2}{k_1}, b = \frac{b_2 k_1 - b_1 k_2}{k_1}$.

The rf amplitude is obtained by comparing the slope of the line (6), $\alpha = \arctan(k)$, with the calculated one. The value of U_φ corresponding to a synchronous phase can be found by solving the equation $\Delta\varphi_A = a_{11}\Delta\varphi_1 + a_{12}\Delta\varphi_2 = 0$ and equations (4) and (5) to give:

$$U_{\varphi_s} = -\frac{b_1 a_{11} + b_2 a_{12}}{k_1 a_{11} + k_2 a_{12}}. \tag{7}$$

The input beam energy ΔW_A is determined as a solution of eq.(6) and the second equation of the system (2):

$$\Delta W_A = \frac{b_2 k_1 - b_1 k_2}{k_1} a_{22}. \tag{8}$$

The measured Δt data are shown in the Fig. 6. The

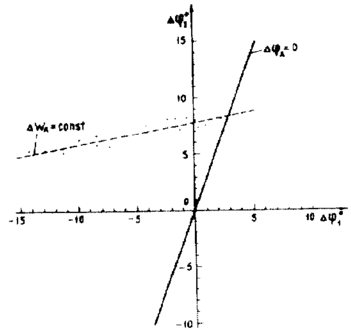

Figure 6: Experimental results of Δt measurements.

fitted line is a phase variable line for the design rf field amplitude and corresponds to constant input energy. In accordance with equation (7) the difference between the input beam energy and the synchronous one is $\Delta W_A = -42keV$.

5 CONCLUSION

In order to set coarsely the rf parameters, the beam current for separated energy, the bunch harmonic signal as well as the absolute energy of the beam are measured as a function of the rf phase in the module being adjusted. In order to avoid amplitude and phase setting errors in a multi-cavity ion linac the Δt design values must be generated by a multi-particle simulation code. The description of the Δt measurement technique in the INR linac is given.

6 ACKNOWLEDGEMENT

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7 REFERENCES

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