SETTING OF RF PHASE AND AMPLITUDE IN MULTI-TANK ION LINAC

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Abstract

This paper describes solutions to the problem of setting RF phase and amplitude in a 600 MeV proton and H^- linac. Various tune-up procedures have been developed depending on the longitudinal beam dynamics along the linac. In addition to the well known absorber method for DTL and the Δt procedure for the high energy part of the accelerator, a tune-up method based on the measurements of phase spectrum, momentum spread, absolute energy as well as time-of-flight are used.

Introduction

The INR linac consists of two gap buncher, five Alvarez tanks at 198.2 MHz followed by 28 DAW modules at 991 MHz. In a multi-tank linac, it is difficult to set phase and amplitude in each accelerating cavity. Phase scan measurements are successfully used in order to set the rf field amplitudes and phases on the two buncher cavities and the first four DTL tanks. In this measurement, the rf phase in a tank N is scanned with respect to the phase of the beam from tank N − 1, while detecting the intensity of the accelerated beam beyond an absorber.

The fifth Alvarez tank of the INR linac is used to match the beam longitudinally into the acceptance of the DAWL. Therefore the tuning of this tank must be done with special care.

The first five DAW modules are turned on by using the Δt procedure [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 several tune-up methods have been proposed and studied.

DTL Tuning

In phase scan measurements the rf phase in a tank N is scanned with respect to the phase of the beam from tank N − 1, while detecting the intensity of the accelerated beam beyond an absorber. There is a set of absorbers for which thickness are calculated to discriminate the unaccelerated particles beyond each tank.

The typical phase scan curves are presented in the Fig.1. By using these curves, the bucket phase width at half maximum is determined for various rf field levels and fitted to theory using a least square method. This

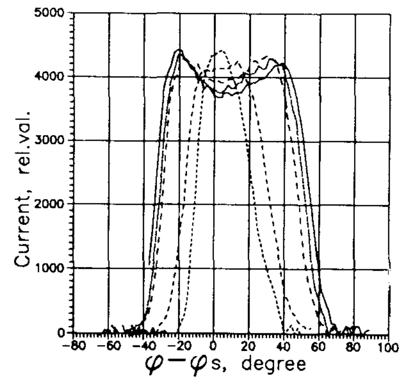

Figure 1: Tank 2 phase scan, rf field level is a parameter

process determines the rf field amplitude and phase to a precision of 1% and 1° respectively at 99% c.l. Time-of-flight measurements are made by using the beam harmonic monitors (BHM) operating on the third harmonic of the DTL rf frequency. In the phase scan experiments the amplitude of the induced signal in the BHM installed downstream the tank being adjusted is similar to phase scan curve obtained by using the absorber. The dependence of the third harmonic intensity from the rf phase of the tank being adjusted can be used for setting the rf field parameters. Once calibrated by using of the absorber method this procedure works with the same precision (1% and 1°) but does not disturb the beam.

The main feature of the longitudinal matching is that the operating frequency of the second part of the linac is five times higher that of the first part and, consequently, its longitudinal acceptance is five times smaller. The length of final (fifth) resonator of the DTL is a quarter of a longitudinal oscillation wavelength which makes it possible to reduce the bunch phase length by a factor of 1.4 and thus fit the beam safely into the acceptance of the DAWL. Therefore, the tuning of this cavity is especially important. For this goal several independent turn-on procedures have been developed which are based on the following measurements: 1) time-of-flight; 2) the intensity of the beam at a fixed energy as selected by a spectrometer; 3) phase spectra. The phase difference between the induced signals in the BHMs upstream (A) and downstream (B) of the tank:

$$\Delta\varphi_B = \varphi_{ABoff} + \varphi_{ABon} \quad (1)$$

verses the phase of the rf in the tank is presented in

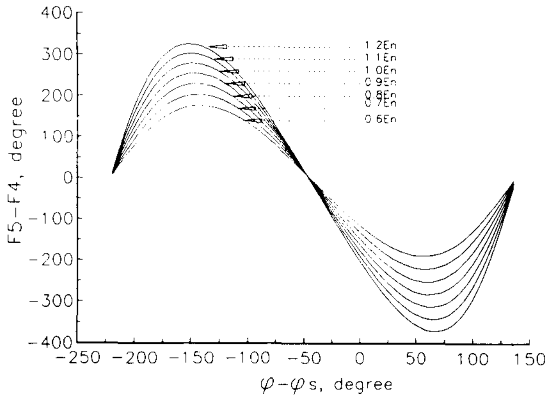

Figure 2: Tank 5 phase scan, rf field level is a parameter

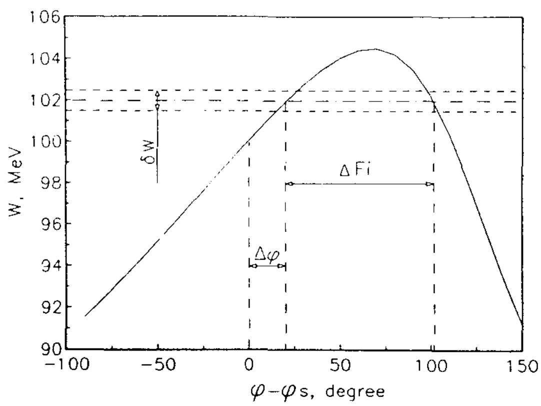

Figure 3: Tank 5 output beam energy vs accelerating field phase

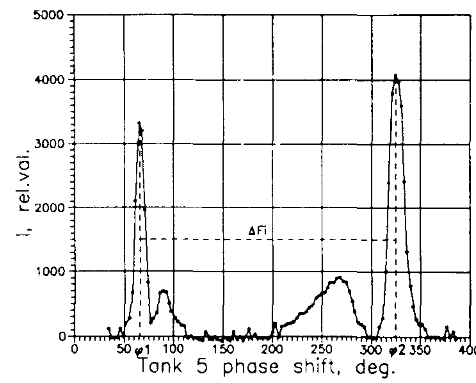

Figure 4: Spectrometer output signal vs accelerating field phase

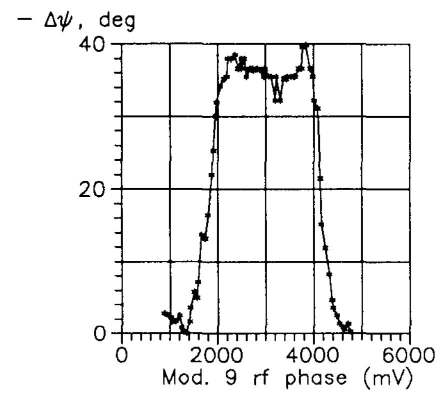

Figure 5: Phase difference vs rf phase of module #9.

Fig.2. The synchronous phase is determined relative to the intersection points of the x-axes and the sinus shape curves - the location of these points does not depend on rf field level in the tank. The amplitude of this curve is compared with calculated one in order to find rf amplitude in the tank.

The second method for determining the synchronous phase is the measurement of the average energy as the phase in the matching tank is varied (Fig.3). The magnetic spectrometer is tuned to separate the energy of $W_0 \pm \delta W/2$, where δW is the spectrometer resolution and W_0 is the input energy. As the phase is varied the beam intensity downstream of the spectrometer is measured. The result is two sharp peaks with a distance between them ΔF (Fig.4). The measurements are repeated for other spectrometer energies $W_0 + \Delta W$, where ΔW is known with the high precision. The measured value of ΔF must correspond to the calculated one with the periodicity of 2π. The synchronous phase is determined relative to the locations of the measured peaks.

DAWL Tune up Procedures

The coarse methods for setting the rf parameters as well as the Δt-procedure for early modules in the INR linac are described elsewhere [2]. In order to set coarsely the rf parameters for modules in the energy range of 160-600 MeV, the change in the value of the beam energy 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 pair of BHMs at every third module. Then, the beam passing through the two detectors induces a phase difference in the measuring circuits. The measured phase difference vs rf phase at module #9 is shown in Fig. 5. The measured Δt data are shown in the Fig. 6. The fitted line is the phase variable line for the design rf field amplitude and corresponds to a constant input energy. The Δt application for the low energy part of DAWL up to 250 MeV shows that the relative input energy displacement from design value is in the range of $(0.03 - 0.1)\%$.

For higher energy modules the slope of the variable phase curve is not sensitive to the rf field change. Therefore the synchronous phase is determined by finding the intersection point of the experimental phase variable

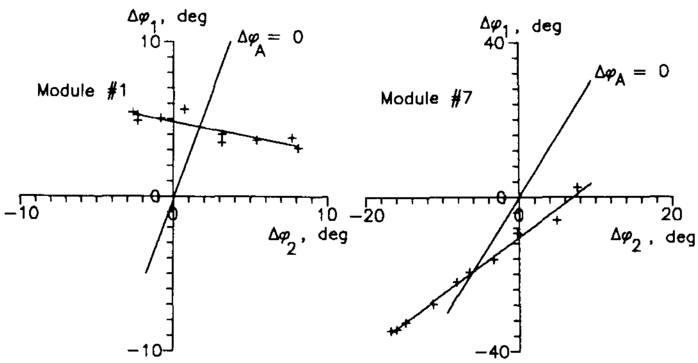

Figure 6: Experimental results of Δt measurements.

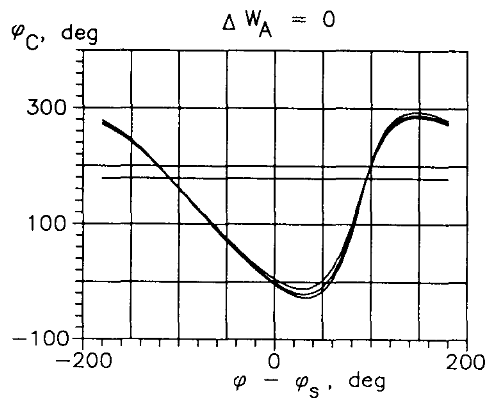

Figure 7: Phase difference $\Delta\varphi_{AC}$ vs rf phase of module #21 with rf amplitude in a range of $\pm 5\%$ as a parameter.

curve for the input energy ΔW_A=const with the perpendicular to the line $\Delta\varphi_A = 0$ in the Δ t-plane [1]. However, this method will produce an erroneous synchronous phase determination if the energy of incoming beam is displaced relative to the design value. We have made a computer simulation of a possible turn-on procedure which allows us to set the phase independently from the incoming energy displacement ΔW_A as well as to find the value of ΔW_A. To do this, the time-of-flight t_{AC} is measured for the full range of the rf phase adjustment (see Fig. 7). To find the incoming energy displacement as well as the synchronous phase a horizontal line is drawn which is located in the proportion a/b from the extrema of the phase scan curves. A computer simulation allows determination of the ratio a/b which avoids a dependence of the distance ΔF between the intersections of this line and the measured curve on the rf amplitude in the module. Then this distance ΔF depends on ΔW_A only. The sensitivity of this method is $3° - 1°$ per 0.1% of the incoming energy displacement ΔW_A in the energy range 200 - 600 MeV in the INR linac.

CONCLUSION

The setting of the rf field amplitude and phase in a DTL is done by using the absorber method with the precision of 1% and 1° respectively for 99% of probability. The Δt procedure has been successfully used for the low energy part of the DAWL up to 250 MeV which shows that the input relative energy displacement from the design value is in the range of $(0.03 - 0.1)\%$. Additional measurements in the higher energy modules are required to exclude errors in the setting of the rf parameters from the incoming energy displacement.

ACKNOWLEDGEMENT

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