The Delta-T Tuneup Procedure for the Fermilab Linac Upgrade

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Abstract

The analysis necessary to perform the delta-t procedure for setting module phase and electric field amplitude on the upgraded linac at Fermilab is described. Two distinct delta-t methods are required to tune all of the modules in the linac upgrade. The accuracy and stability of each method has been calculated as a function of linac module number. A procedure for coarse tuning of the linac is also presented. Coarse tuning is necessary to bring the module phase and amplitude into ranges where the delta-t method is accurate and reliable.

I. INTRODUCTION

The delta-t procedure is a time-of-flight technique in which beam transit time changes are recorded as rf power is turned on and off in a module. The time-of-flight changes can be used to infer phase and electric field amplitude settings within a module. The procedure was developed at the Los Alamos National Laboratory many years ago for the purpose of tuning the phase and amplitude of accelerator modules along the LAMPF linear accelerator [1]. Recently, use of the procedure has been proposed on a number of other linear accelerators [2-4].

Under current plans, the procedure will be used to set the phase and amplitude of the upgraded linear accelerator at Fermilab. The delta-t procedure will first be carried out on the existing 200 MeV linear accelerator in order to test the hardware and understand some of the practical problems associated with the procedure. Initial experiments on the existing linac were described in earlier work [4,5].

The upgraded linear accelerator, currently under construction at Fermilab, will be a 400 MeV device [6]. It will consist of seven modules, each powered by a 12 megawatt klystron. The modules are divided into 4 sections, each separated by a drift distance of $3\beta\lambda/2$. Side-coupled structures having constant cell lengths of $<\beta>\lambda/2$ make up the sections, where $<\beta>$ is the average beta for a particular section. The fundamental resonant frequency of the modules is 805 MHz.

An assumption in the theory of the delta-t procedure is that the initial phase and energy displacements from design values are small. For small displacements, the phase and energy displacements at the output of a module can be linearly related to the phase and energy displacements at the input to a module. Coarse tuning must be performed before the delta-t procedure is used in order to remain within this linear region. In addition, for some of the low energy modules, ambiguities can occur in bringing a module into tune if the initial settings deviate too much from design. A coarse tuning procedure will be described in the next section.

II. COARSE TUNING PROCEDURE

The technique for coarse tuning utilizes measurements of the energy change through a module as the module phase is varied. Energy changes can be determined from measurements of time-of-flight changes similar to those used in the delta-t procedure. Beam phase changes at two beam monitors placed after the cavity are recorded as the power to the module is alternately turned off then on. These phase changes are then converted to time-of-flight changes. The changes in velocity through a module are calculated from,

$$\frac{\Delta v}{v_i} = \left\{ \frac{1}{1 - \frac{(\Delta t_2 - \Delta t_1)}{D} v_i} - 1 \right\} \tag{1}$$

where v_i is the velocity entering the module, D is the distance between the two beam monitors used in the measurements, and $\Delta t_{1,2}$ are the changes in the times-of-flight as rf power is turned on and off. The energy changes are calculated from equation 1 and the relation, $\Delta W = E_r \Delta\gamma$, where E_r is the rest energy of the beam particles.

As a first step in the coarse tuning procedure, the electric field amplitude within the module is increased from zero until the peak energy change through the module equals the calculated value for the design particle. The cavity phase is then set to the calculated value relative to the phase at which the peak energy change occurs. Values for the phase and energy displacement at the peak energy for the linac upgrade are given in Table I. The above procedure can bring the linac within a few degrees of final tune if the input energy displacement is zero.

Tests of the coarse tuning procedure will be made on the existing 200 MeV linac at Fermilab, before it is used on the upgraded linac. Figure 1 contains plots of the energy displacement versus module phase calculated for a module at about the middle of the existing linac. The average axial electric field on axis varies from zero to 2.6 MeV/m in the figure. The design field is 2.6 MeV/m. A sharp energy

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Table I
Phase and energy displacement of the peak in energy

Upgrade Module	Phase (degrees)	Energy (MeV)
1	46.07	2.57
2	47.15	3.31
3	46.91	3.99
4	45.77	4.59
5	44.37	5.13
6	43.62	5.73
7	42.26	6.15

peak and a strong sensitivity to electric field amplitude are demonstrated.

III. ACCURACY AND STABILITY OF THE DELTA-T PROCEDURE

This section provides a brief summary of results described in a much longer paper contained in the Fermilab Linac Upgrade Document File [6]. Two separate delta-t methods may be used to tune the upgraded linac. Applying Method 1, deviations from design in the changes in the times of flight through a module are measured at two positions after the module being tuned. The deviations in time-of-flight changes can be related in a linear fashion to the phase and energy displacements, as described in reference 1. Module phase is then adjusted until the output energy displacement is zero.

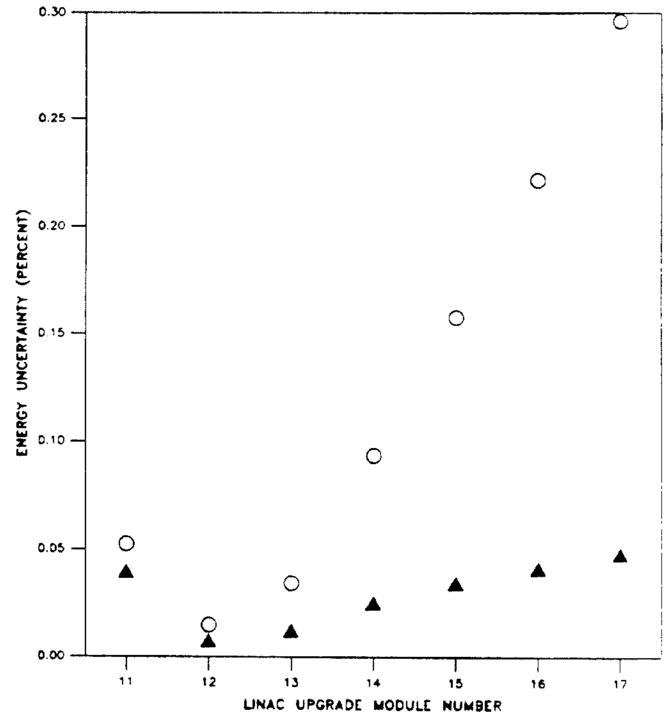

Figure 2. *Output energy uncertainty for 13.8 picosecond random error in time measurement. Circles - Method # 1 triangles - Method # 2. The two methods are described in Section III.*

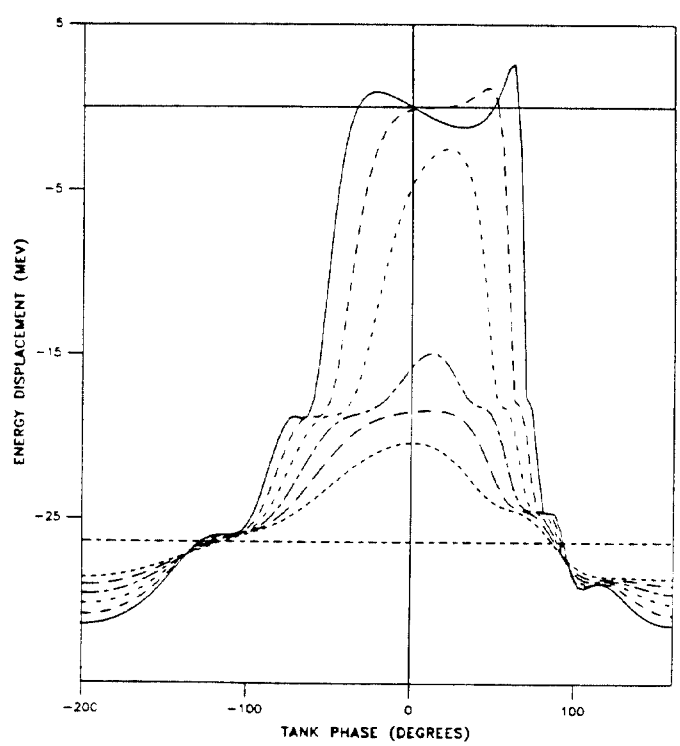

Figure 1. *Energy displacement versus tank phase for tank number 4 of the existing Fermilab Linac.*

This first method loses accuracy in the higher energy modules of the linac, and a second method is used to preserve accuracy. Applying Method 2, the phase of the module is adjusted until it intersects a target line which has been chosen to optimize accuracy, according to a prescription given in reference 1.

A plot of the output energy uncertainty for each of the two delta-t methods, applied to the upgraded linac at Fermilab, is shown in figure 2. A random error in the time measurement of 13.8 picosecond is assumed in thecalculations which generated figure 2. The input energy displacement is assumed to be zero. The figure shows that much greater accuracy is achieved for Method 2 after the second module in the upgraded linac. Accuracies for both methods are similar in upgrade modules 1 and 2.

In the absence of other information, it would seem logical to use Method 2 over the entire linac. Unfortunately, in the early modules of the linac, energy displacements can grow along the linac for Method 2. The process is analogous to the growth of an instability. Figure 3 demonstrates this problem, where a parameter called the stability ratio, defined in reference 1, is plotted for each of the upgraded linac modules. The stability ratio is the ratio

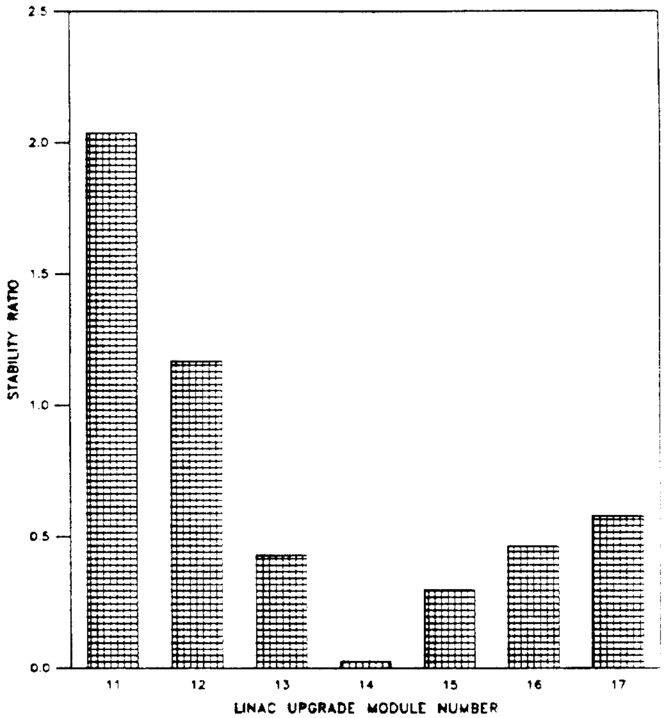

Figure 3. *Stability ratio for Method # 2 in the Fermilab Linac upgrade.*

of output energy displacement magnitude to input energy displacement magnitude multiplied by the ratio of input energy to output energy.

The stability ratio must remain less than one to insure good confinement within the longitudinal acceptance area. The stability ratio for the first two modules of the linac upgrade is greater than one. Since only two modules are involved, the "instability" acts over only a very short distance. Nonetheless, to avoid potential problems, Method 1 should probably be used over the first two modules of the linac.

IV. SUMMARY AND CONCLUSIONS

Coarse adjustment of the electric field amplitude of each module of the upgraded linac at Fermilab can be made by increasing the amplitude until the peak energy change through the module equals the calculated value for the design particle. The phase can then be set to its calculated value relative to the peak energy. Subsequently, the delta-t procedure is used to fine tune the modules. The analysis indicates that two distinct delta-t methods should be used to tune the entire upgraded linac. Method 1 should be used for modules 1 and 2, while method 2 should be used for modules 3-7.

V. REFERENCES

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