An Automatic Procedure to Find and Set the Shift Phases for the Superconducting Resonators in the ALPI Accelerator

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Abstract

ALPI is a linear post-accelerator (Linac) of a 15 MV XTU Tandem, and its accelerating elements are 59 quarter wave superconducting resonators. The Linac may boost beams of several ion species, with different state of charge, at various injection energies.

The Linac set-up procedure, involving the magnets, the diagnostics and the RF control systems, takes from 10 to 48 hours of continuous work. From 5 to 10 hours are usually necessary to find the shift phases for the resonators.

A procedure was recently developed to perform this last task, in order to decrease time and man-power necessary for the Linac set-up.

1 Introduction

The superconducting Linac ALPI was designed to accelerate bunched beams of several ion species, injected from the Tandem. All its RF resonators operate in self-excited loop mode and are independently phased through digital phase shifters with respect to a common reference at 160 and 80 MHz, [1]. The resolution of the digital phase shifters is 1.4°.

To achieve the maximum available energy gain with a high transmission rate each resonator has to be set to an unique accelerating or bunching phase, which is -20° with respect to the top of the RF common reference for the accelerating elements and -90° or +90° for the bunching and de-bunching elements, see Figure 1.

The correct set of shift phases depends on the type of beam (ion mass, state of charge), on the injection energy and on the configuration of the pulsing system. Even for beams of the same type, the sets of fields and shift phases for the resonators cannot be generally re-used in different runs, because small differences in the initial sections of the Linac may produce great differences of the beam characteristics in the final sections. This is due to various reasons: for instance the beam injection energy may be slightly different form run to run. An other reason is that the cavities can not always be all powered at the same accelerating fields: sometimes the fields must be decreased for some resonators, or, if further RF conditioning could be performed, they may be set again to higher values. Therefore for each new run all the resonators are always phased from the first to the last, one by one, in sequence, [2].

During the commissioning of the ALPI accelerator the whole Linac set-up have been a procedure lasting about 48 hours. Now this period has been decreased to an average period of 24 hours but from 5 to 10 hours are still necessary for the manual phase locking procedure.

Because of the effort necessary to find the set of correct shift phases, and because human errors in this procedure may produce a final beam of bad quality, a decision was taken to develop an automatic procedure to perform this task.

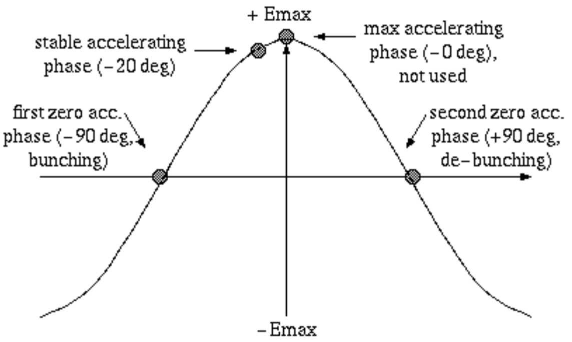

Figure 1: the standard accelerations and bunching phases for ALPI.

2 The method

In the ALPI Linac the resonators are placed in two parallel arrays connected by a U-bend; after a final L-bend a transport line brings back the beam to the experimental rooms. Two special wider beam profile monitors (30 mm grids) each including an horizontal grid of 39 wires are placed immediately after the first 90° bending magnet in the U-bend at the end of the first low-energy branch (diagnostic box DU2) and after the L-bend at the end of the high-energy branch (diagnostic box DE2) as shown in Figure 2.

To find the resonator shift phases, the 90° bending magnet in the U-bend and in the L-bend are operated in a dispersive mode and, for each of them, the following steps are executed:

- the beam profile is centred on the horizontal grid with the resonator switched off;
- the resonator is switched on, it is locked and the phase shifter is scanned as long as the beam profile is brought back in the centre of the horizontal grid (this a "zero acceleration phase", -90° or +90°);
- by the displacement of the beam profile as a consequence of a small positive change of phase, the two different "zero acceleration phases" may be distinguished and the -20° "standard" shift phase may be found and set;

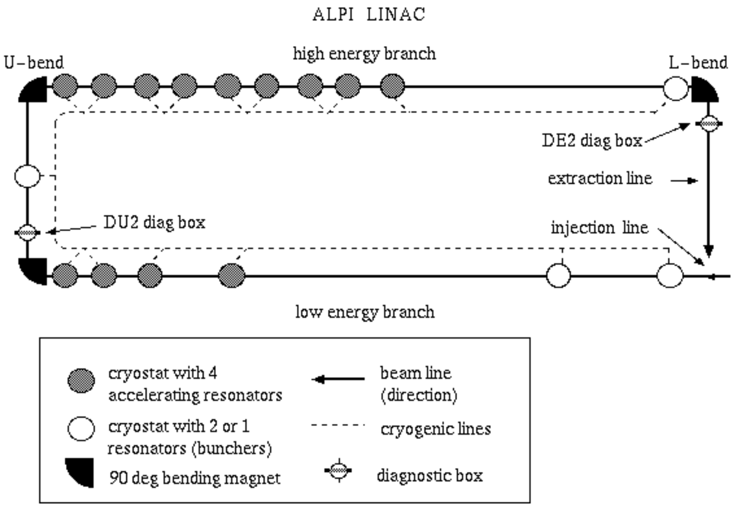

Figure 2 - ALPI Linac layout

- the bending magnet is adjusted to centre again the beam on the horizontal grid; a new cavity may now be set (see Figure 3).

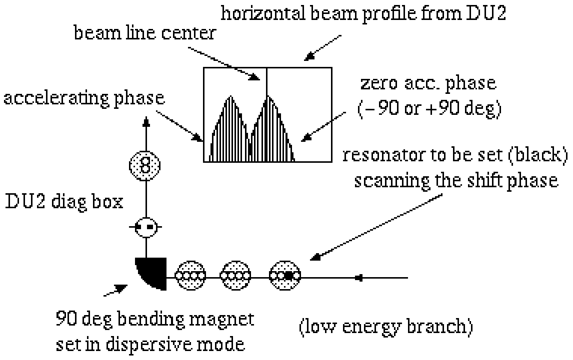

Figure 3 - The search method for the correct shift phase

3 Automation and first tests

In 1995 the development of an automatic procedure working through the same steps performed by the operators was started. For this aim some changes had to be done on the control system: a software communication path had to be established between the RF control system, where the phase shifters are to be scanned, and the diagnostic system, where the beam profile data are available. A client/server mechanism using UDP/IP protocol was added to the two systems to connect them and to have the beam profile data readable from the RF control system.

Some data filtering had to be added to the diagnostic system, to reduce the various types of noise on raw data and to summarise the beam shape on the horizontal grid with two parameters to be used in the search algorithm:

- a customisable time averaging was added, to reduce white noise on data, based on past T samples ($i(t_k)$):

$I_n(t_k) = 1/T\cdot\{ \Sigma_{j=0,T-1}\, i_n(t_{k-j}) \}$ (wire n, time t_k)

- a hand-set linear interpolation was added, to correct zero or saturated wire currents (corresponding to broken or short-cut wires on grids):

$I_n(t_k) = [\, I_{n-1}(t_k)+I_{n+1}(t_k)\,]/2$ (wire n, time t_k)

- on-line computation of the beam area (I), of the beam position (X_c), and of the beam width (X_w) were added, to detect the presence of the beam on the horizontal grid and to check its position and width, at time t_k:

$I(t_k) = \Sigma_{n=-N,+N}\, I_n(t_k)$

$X_c(t_k) = \{\Sigma_{n=-N,+N}[n\cdot dx\cdot I_n(t_k)]\}/I(t_k)$

$X_w(t_k) = \mathrm{sqrt}\{1/I(t_k)\cdot\Sigma_{n=-N,+N}[(n\cdot dx)^2\cdot I_n(t_k)]-X_c^2(t_k)\}$

where dx is the distance between wires and 2N+1=39 is the total number of wires in a grid.

This first automation of the Linac set-up does not involve the operations on the magnets, which have to be adjusted manually after the shift phases have been found: it only searches for the shift phases in sequence, on demand.

The search algorithm is based on the following steps:

- the horizontal beam area I on the horizontal grid is computed with the resonator off,
- the shift phase is set to an initial value, then the resonator is powered on and locked (usually the beam disappear from the horizontal grid, i.e. the area I decreases to zero),
- the shift phase is scanned as long as the beam area I grows to a minimum value (usually 50% of the initial area); this means the beam is again on the horizontal grid; the position X_c of the profile is then monitored,
- the first shift phase that sets to zero the horizontal beam position X_c (beam centred on the horizontal grid) is the first "zero phase", this phase, its type (-90° or +90°) and the horizontal beam width X_w in this situation are recorded,
- the second "zero phase" is found and recorded with the

same technique,
- the "zero phase" corresponding to the most narrow shape is used to calculate the shift phase.

This algorithm was tested several times at the end of runs where the Linac had been put in operation manually; the results of these initial tests were satisfactory, showing a general good agreement between the two sets of shift phases (not more than 2° of difference).

4 Problems, solutions, future developments

While testing the above described automatic procedure several unexpected problems arose.

The first is that for certain beams and for some positions of the resonators the horizontal profile may become very large, often exceeding the size of the grids; in this situation the values of convergence thresholds for the search algorithm may be critical. This problem was at first solved with a fine tuning of these thresholds, but will be better overcome by an auto-tuning mechanism.

An other initial random source of faults came from the RF power amplifiers, which may suddenly shut down (because of a hardware protection) as a consequence of a change in the shift phase (simulating a "false" zero phase). A check had to be added on the status of the amplifier at each research step. A recovery mechanism should be also added to start again the search when this kind of error occurs.

The most difficult problem to be solved comes from the digital phase shifter, which may have infrequent but sudden faults whose consequence is a "jumping" behaviour of the horizontal movement of the beam, a situation which is rather difficult to be detected automatically. Probably the best solution to this still open problem will be a separated check procedure to be performed on all the phase shifters just before run-time.

In the next months the development of new code has been planned that will allow to adjust automatically the bending magnets after the correct setting of each resonator.

5 Conclusions

After some first adjustments the above described procedure proved to be reliable enough to be used in normal Linac set-up and has become a standard tool during the ALPI runs.

A further reduction in the time and man-power necessary for the whole Linac set-up is expected by the automatic adjusting of the bending and focusing magnets.

References

[1] G. Bassato, A. Battistella, M. Bellato and S. Canella, Nucl. Instr. and Meth. A328 (1993), pp. 195-198

[2] A. Dainelli et al., Nucl. Instr. and Meth. A382 (1996), pp. 100-106