UPGRADE OF THE ISAC DTL TUNING PROCEDURE AT TRIUMF

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Abstract

The TRIUMF ISAC facility has two variable energy heavy ion linacs as post accelerators for radioactive ion beams. The ISAC I linac is a warm IH-DTL with five accelerating tanks and three bunchers, the ISAC II linac uses twenty independently phased superconducting cavities. The first linac operates between 150keV/u and 1.8Mev/u; the second boosts the 1.5MeV/u injected beam by 20MV. The DTL is tuned based on the energy spectrum from an analysing magnet. The superconducting linac is tuned on energy and time profiles with a diagnostic based on a gold foil scattering ions to a silicon detector. The silicon requires lower beam intensity. Furthermore the tuning time is reduced and streamlined by means of a MATLAB graphical user interface. This interface uses a simple cosine model to characterize the energy gain versus RF phase of each cavity. Based on this we have pursued a new tuning procedure for the DTL using a gold foil/silicon detector diagnostic. The more complex RF structures of the DTL require measurements and beam dynamics simulations (done with the LANA code) to produce a model for a dedicated MATLAB interface. In the paper we describe the two existing tuning methods and present the new DTL procedure and interface.

INTRODUCTION

The ISAC facility has three experimental areas. The low energy area uses the beam at source potential while the other two use post accelerated beam in different energy ranges. The overall view sees a total of ten experimental stations ready to take beam. In such a scenario reducing the tuning time is essential to increase the amount of integrated beam on target. In the case of post accelerated beamlines most of the time is spent tuning the linacs, the DTL in ISACI and the superconducting (SC) linac in ISACII. The DTL [1] is composed of eight RF modules (see Fig. 1): five accelerating IH structure tanks and three bunchers between the first four tanks. Between tanks there are triplet of quadrupoles for the transverse focusing. The ISACII linac [2] is composed of five cryomodules each containing four bulk niobium superconducting cavities and a superconducting solenoid.

The DTL tuning diagnostic is a 90° analysing magnet (PRAGUE magnet). Placed 7.6m downstream of the DTL after a high energy transport line (HEBT)(see Fig. 2), the PRAGUE disperses the energy of the beam on a transverse profile monitor (PRAGUE harp). Due to the limited energy spectrum displayed by the harp the magnetic field needs to be changed as we change the beam energy. As well the HEBT optics must be corrected to transport the beam to the harp where we require at least 1 enA to have a good signal.

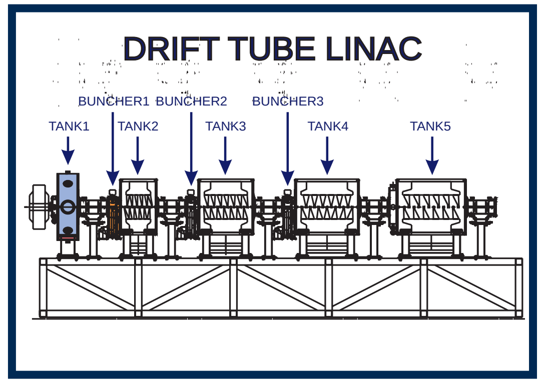

Figure 1: Layout of ISAC DTL

The SC linac uses instead a silicon detector (SID) [3] that intercepts part of the beam scattered by a gold foil that can be inserted on axis. The gold foil/SID is 4.6 m downstream of the linac after a quadruplet (see Fig. 2). The SID needs much lower beam current (hence the use of a gold foil) and it gives information about the time and the energy spectrum that covers the entire range of energies accelerated by the linac. The correct optics in this case is not critical as long as a few hundred particles can reach the SID.

TUNING PROCEDURE

The tuning procedures of the DTL and the SC linac are different. Both machines can fully deliver a particular range of energies.

Although a variable energy machine, the DTL modules have a fixed velocity profile. Each module can reach a designed maximum energy. The DTL accelerates ions from 150 keV/u up to 1.8 MeV/u for $2 \leq A/Q \leq 6$. The maximum gradient at which each module operates is scaled according to the A/Q. The number of modules tuned depends on the final energy. The amplitude of the last module is detuned to set the final energy. The DTL also injects the beam into the SC linac at 1.5 MeV/u.

The SC linac operates at fixed voltage for a total of 20MV of acceleration. Each cavity is independently phased. The number of cavities turned on determines the final energy. The gradient of the last cavity turned on is reduced to set the final energy.

The DTL procedure is slightly complex and requires some experience in order to reach the proper beam quality. The SC linac tuning procedure is more intuitive and, thanks to the MATLAB interface, straightforward.

DTL Procedure

The first step of tuning is coasting the injected beam at 150 keV/u through the DTL to the PRAGUE harp. Here the energy profile is centered selecting the proper field of the PRAGUE magnet.

We then set up the MEBT buncher (see Fig. 2) focusing the beam in time at the entrance of the DTL. The buncher is phased at -90° synchronous phase (no acceleration) and the amplitude is set to minimize the time spread. Reducing the time spread looking at the energy profile requires experience of tuning and the final result is in some way subjective.

After the buncher is tuned we turn on the first tank at a low gradient. It is important to start with a low gradient otherwise the acceleration of the tank is so strong that the beam signal is lost at the harp. We phase the tank at 0° synchronous phase (maximum acceleration). In order to find the zero degree we keep moving the RF phase as long as the energy profile at the harp moves toward acceleration. Once we found the correct RF phase we increase the gradient to reach the maximum energy of the tank as per the DTL beam dynamics. While we move the RF phase or increase the gradient we must also change the field of the PRAGUE magnet and reset periodically the optics to maintain a reasonable signal inside the limited harp range.

After the first tank is set we tune the first buncher. This, turned on at low gradient, is phased at -90° if the final energy is now correct. If this is not the case we phase the buncher at -45° providing both bunching and acceleration to the beam. The gradient of the buncher is set to reduce the energy spread in the first case or increased to reach the maximum energy set by design in the second case. Again as we step up in energy we need to change both the PRAGUE field and the optics.

The rest of the modules are tuned in the same way according to the final energy.

Superconducting Linac Procedure

We start coasting the injected beam at 1.5 MeV/u to the SID. The time and energy data are processed u sign MATLAB and displayed in a graphical user interface (GUI). The two spectra are processed by fitting them with gaussian curves that give the centroids and the widths (in term of σ).

The DSB buncher (see Fig. 2) focuses the beam in time at the entrance SC linac. The buncher is phased at -90° looking at the energy spectrum for no acceleration (no change in the centroid position). The amplitude is instead set looking at the time profile minimizing the σ_T of the gaussian fit. This minimum is found plotting the sigma versus buncher amplitude data pairs and interpolating them with a second order polinomian curve. The amplitude associates to the minimum is then rescaled, based on distances, to bunch the beam at the entrance of the linac.

After we set the buncher we tune one by one the superconducting cavities. For each cavity we collect five data points of energy gain, in terms of SID channels, versus RF phase. These points are interpolated with a cosine curve and hence the 0° synchronous phase (maximum acceleration) calculated. Each cavity is then phased at -25° synchronous phase.

In the GUI we have the option to select the time signal in alternative to the energy. Moreover from the interface we control the phase and the amplitude of the RF cavities.

Since the SID requires only a few hundred counts per second, the optics doesn't need frequent tuning. Typically we change the solenoids and the quadrupoles setting after tuning a cryomodule.

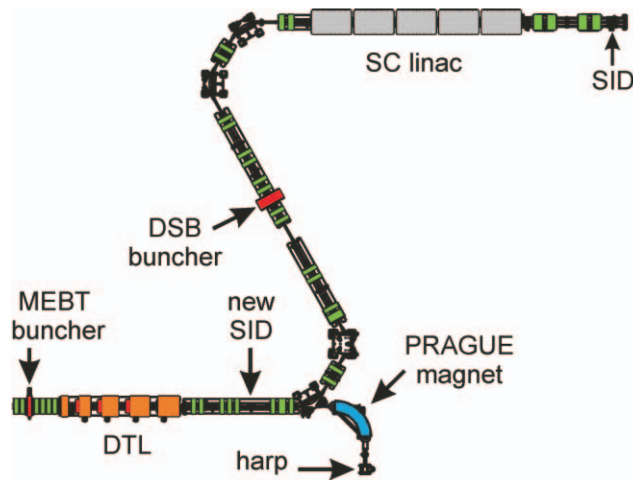

Figure 2: Overview of the DTL, SC linac and tuning diagnostics.

BEAM DYNAMICS SIMULATIONS

Our goal is to apply the tuning procedure of the superconducting linac to the DTL taking advantage of the same type of diagnostic. In order to pursue this goal we recently installed a phasing monitor (gold foil and SID) 3.6 m downstream of the DTL (see Fig. 2). The characteristic curve RF phase versus energy gain is different for a DTL tank due to the more complex RF structure. The curves are generated running beam dynamics simulations with the LANA code [4]. These simulations show that each tank has its own characteristic curve quite different from a simple cosine.

The LANA files used in the simulations are the same used to design the DTL [5]. The entrance Twiss parameters and emittances are: α=1.4, β=0.24 mm/mrad and ε_N=0.4 π mm·mrad for the transverse phase space and α=-0.2, β=0.053 ns/keV/u (3 deg/% at 106.08 MHz) and ε=1.03 π keV/u·ns (26 %·deg at 106.08 MHz) in the longitudinal. Note that the design longitudinal emittance is 1.5 keV/u·ns while the used value comes from a real measurement: when we bunch the beam in time at the SID we have an upright ellipse in the longitudinal phase space. We then measure the energy spread at the PRAGUE harp and hence we calculate the longitudinal emittance. Initial simulations used one particle, but the latest runs use 5000 particles to better represent the energy and time profile we see at the SID.

DATA ANALYSYS AND ONLINE RESULTS

Through the simulations we produce for each modules (we consider also the bunchers even though their curves are very close to a cosine) a list of data pairs (RF phase,energy gain) for phases between -360 and 360 degree in step of 20. These data are then analyzed using a Fourier series in order to find the proper fitting curve for each module. The Fourier coefficients are found numerically using a routine based on the least square method. The number of harmonics is cut as soon as the sum of the squared residuals doesn't improve significantly. For our purpose ten harmonics are enough. The curves are the most important result of the analysis since we need them to interpolate the real data coming from the machine. These curves act as the cosine for the SC linac.

In Fig. 3 (top plot) we can see the characteristic curve of DTL Tank1. The points are the result of the simulations while the solid curve is the result of the Fourier analysis. In the same Fig. 3 (bottom plot) we can see the characteristic curve of the same tank as a result of online measurement. The solid line in this case is the fitting curve deriving from the Fourier analysis: the series of sine and cosine are fed with four parameters A, B, C and D (see Eq. 1) to create a curve that fit the amplitude, the amplitude shift, the phase shift and period length of the real data.

$$g(x) = \sum_{i=0}^{n} Aa_i \cos(B\omega_i x + C) + Ab_i \sin(B\omega_i x + C) + D \tag{1}$$

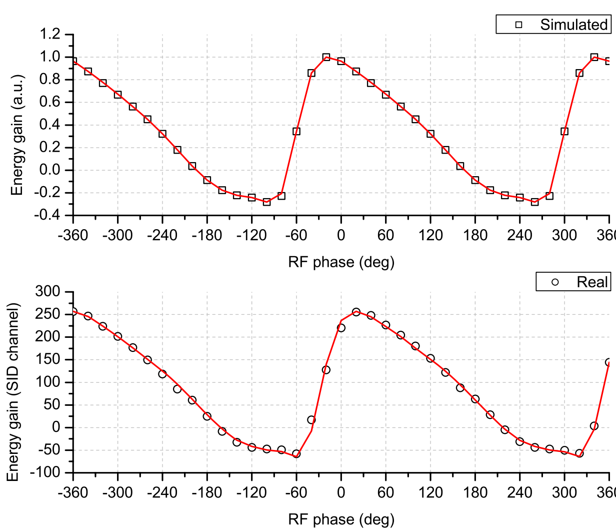

Figure 3: Simulated (top plot) and real data (bottom plot) for DTL Tank1. The simulated data are analyzed with a Fourier series generating a fitting curve. The same curve is then use to fit the real data

For all the DTL modules we successfully interpolate the online measurement using the fitting curves. The new DTL diagnostic allows to turn on the RF modules at the maximum operating gradient (based on the A/Q) and adopt a similar tuning procedure used for the SC linac.

MATLAB APPLICATION

The MATLAB application for the DTL is a replica of the SC linac one. The difference is the use of fitting curve derived from beam dynamics simulations and Fourier analysis instead of simple cosine. In the GUI the time and energy profiles are interpolated with gaussian curves that give the centroid positions and the widths (σ) expressed in channels.

By means of the interface we tune both the MEBT buncher and the DTL modules. The MEBT buncher is phased looking for no change in the energy peak while the amplitude is chosen to minimize the time spread. This amplitude is calculate as for the DSB buncher interpolating the (amplitude,σ_T) data with a second order polinomian curve and rescaling based on the DTL distances. The DTL modules are phased, at maximum gradient for given a A/Q, collecting as many data pairs (RF phase,energy gain) as needed (usually five points are enough). These data are interpolated with the fitting curve and the desired synchronous phase calculated directly in the application.

CONCLUSION

The main advantage of the upgraded DTL tuning procedure is to reduce the tuning time when a complete retune of the machine is necessary. This upgrade is possible thanks to the good simulation model that produces a characteristic curve for each RF module. This procedure uses a new diagnostic based on a gold foil/silicon detector that gives us information on both energy and time profiles of the beam. The energy and time profiles can be easily processed through MATLAB routine and the results displayed in a graphic user interface. The same diagnostic offers also the advantage of operating with very low currents.

REFERENCES

[1] R.E. Laxdal et al., “Beam Commissioning and First Operation of the ISAC DTL at TRIUMF”, PAC’01, Chicago, June 2001, p. 3942

[2] R.E. Laxdal, “Initial Commissioning Results from the ISAC II SC Linac TRIUMF”, LINAC’06, Knoxville, August 2006, p. 521

[3] V.A. Verzilov et al., “Time Domain Diagnostics for the ISAC-II Superconducting Heavy Ion Linac”, DIPAC’07, Venice, May 2007, (to be published)

[4] D.V. Gorelov et al., “Use of the LANA Code for the Design of a Heavy Ion Linac”, PAC’97, Vancouver, May 1997, p. 2621

[5] R.E. Laxdal, “A Separated Function Drift Tube Linac for the ISAC Project at TRIUMF”, PAC’97, Vancouver, May 1997, p. 1194