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IMPROVEMENT OF THE RF FIELD PHASE & AMPLITUDE ERRORS SIMULATION IN TRACEWIN CODE*

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Abstract

RF field phase & amplitude errors are usually not correctly simulated and it is a serious problem especially when in high intensity linear accelerators, the main losses are due to particle leaving the beam acceptance. This new development implemented in TraceWin [1] fixes this issue. The objective is to improve the longitudinal beam dynamics simulation methods, by including more close-to-real models for the cavities tuning procedure. By this way, clear distinction should be done between static and dynamic errors and longitudinal diagnostics accuracy can be clearly defined according to beam dynamics results.

INTRODUCTION

Control of beam losses is the main issue relative to high intensity linear accelerators and most of these losses are due to particle leaving the longitudinal stability making longitudinal acceptance as the key point. The last development presented aims to improve the longitudinal beam dynamics simulation methods, by including more close-to-real models for the cavities tuning procedure. By this way, clear distinction could be done between static and dynamic errors, defined as following:

- Static errors: the effect of these errors is detected and corrected. The strategy of the correction scheme is established to correct their effect.
- Dynamic errors: these errors are not corrected. Effects of these uncorrected errors are simulated by adding them after correction of static errors.

These definitions are translated into TraceWin by several simulation stages allowing to introduce each type of errors at the right step (see Fig. 1).

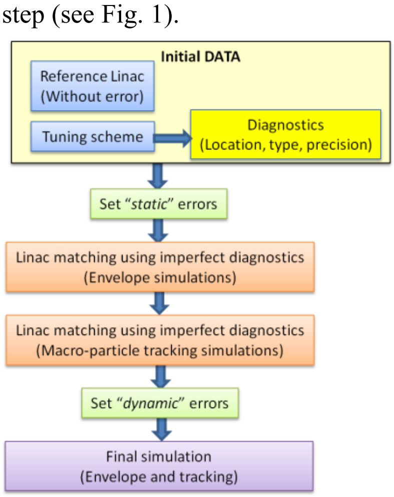

Figure 1: Different steps of a simulation in TraceWin including linac tunings and imperfections.

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DEVELOPMENT

We have to improve cavity model and introduce cavity tuning procedure in simulations replacing the usual scheme by new one, shown Figure 2.

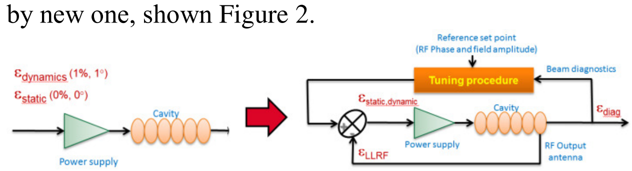

Figure 2: Usual (left) and new cavity scheme (right).

This new development makes TraceWin simulations more consistent, much closer to realistic machine tunings. The main objective is to be able to define the measurement accuracy required for diagnostics involved in the cavity tuning process and check the robustness of the RF tuning process. By this way, the RF static error, usually set arbitrary (to 1°, 1% for example), which make longitudinal transport diverges very quickly, should be compensated by the RF tuning algorithm itself. Some other advantages can be listed:

- Tuning cavity procedure can be checked.
- No arbitrary static errors have to be defined.
- Reducing of the RF errors amplitudes usually requested.
- More consistent simulation.

So, in this new scheme, the static errors are not specified anymore, but built by the diagnostic precision associated to tuning procedure and we are able to clearly simulate the global system making distinction between LLRF errors, diagnostics measurement errors including real correlation between phase and amplitude errors.

CAVITY TUNING

Procedure

Simulating cavity tuning supposes the knowledge of the tuning procedure used in a real machine. The purpose is not to invent new methods, but to implement usual approaches in existing linacs. Based on those experiences, the RF structure is tuned by performing a RF phase and amplitude scan and comparing the measured beam phase and energy with predicted values coming from a model provided by a beam dynamics code. The best match between measurement and simulation can be used to calibrate the RF settings of the accelerating cavity. In simulation code the measured values are replaced by simulation results including structure, RF and diagnostics imperfections and imperfect beam characteristics issue form preceding structures. Typically, it is done by:

- Performing a scan phase of the perfect model.
- Performing a scan phase of the real model.

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- Adjusting the RF field phase and amplitude in the real model to minimize differences between both scans.

The perfect model is given by the transport in the cavity with nominal RF field of the reference beam associated to a measurement without error. The real model is given by the transport in the cavity with real RF field of the real beam associated to a measurement with errors.

Syntax

A specific command has been implemented in TraceWin code. It has to be located in front of the cavity element which has to be tuned. It allows simulating the RF linac cavity tune process and it is valid for all RF accelerating elements (FIELD_MAP, GAP, DTL_CELL, NCELLS…) available in TraceWin. Exact syntax and details are shown in the documentation and its parameters allow to define:

- Range of the RF phase scan.
- Number of scan step.
- Position of diagnostics used.
- Type of measurement (relative or absolute beam phase or beam energy).
- Systematic error or longitudinal BPM position error.
- Diagnostics resolution.

During tuning process, cavities downstream the tuned cavity, are considered detuned without beam loading.

Output Example

Figure 3 shows the TraceWin output result of a cavity tuning procedure. The gray curve (Detuned) shows the initial RF tuning of the cavity which takes into account RF static error set in this example at (20% & 50°). The blue curve is the RF tuning objectives based on perfect model and the red one is the result of the cavity after the tuning procedure. Here, the procedure is based on a RF phase scan of ±75° with 25 steps of measurement. So, starting from the gray curve, the RF amplitude and phase are adjusted to minimize the difference between the results (red curve) with objectives (blue curve). This tuning is not perfect because diagnostics resolution.

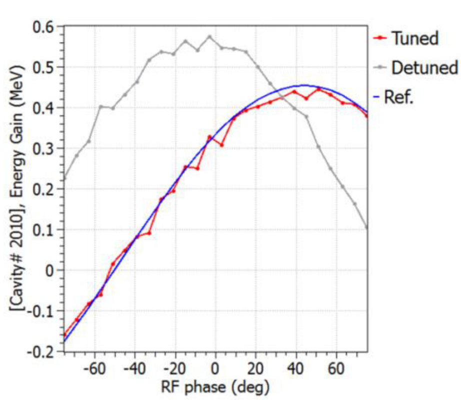

Figure 3: Tuned cavity results example.

MYRRHA LINAC

The objective is to apply this new feature to the MYRRHA linac in order to compare the old simulations method to the new one. Based on the up-to-date start-to-end reference MYRRHA linac layout issue from European project study MAX [2], we consider the machine up to the end of the spoke cavities section and some spoke cavities have been added to increase the output energy from 87 MeV to 100 MeV in order to be closed to the MYRRHA demonstrator, MINERVA. All the following, results are focused on longitudinal point of view, aiming at comparing losses due to particles leaving the acceptance [3].

Reference Simulation

Beam envelopes of the reference case without RF errors and cavity tuning procedure are shown in Fig. 4. Tracking simulation performed with 1.10^6 particles shows no longitudinal losses, see Fig. 5.

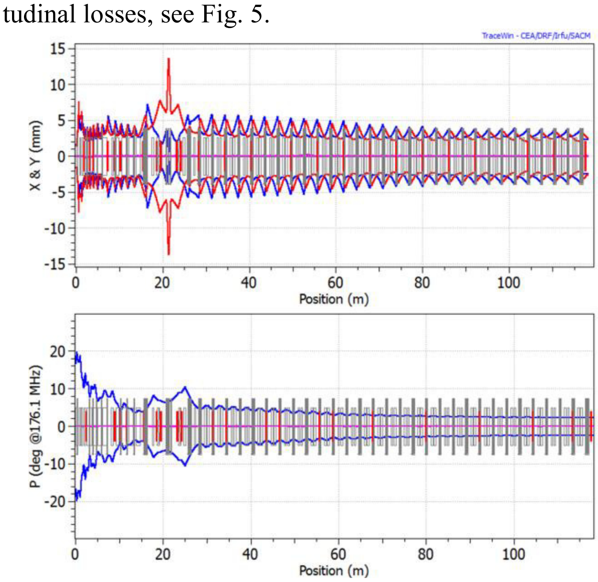

Figure 4: 3 rms transverse and longitudinal beam envelopes.

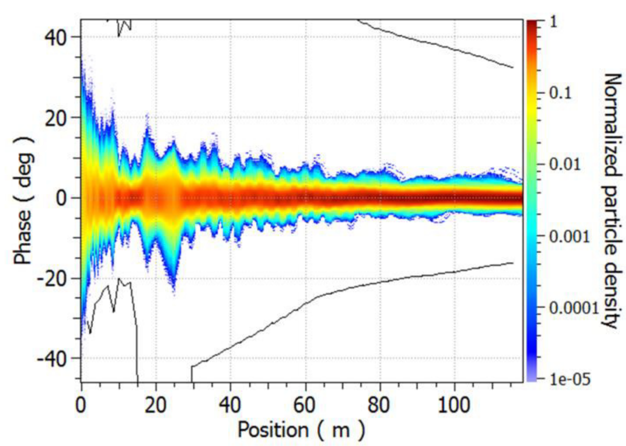

Figure 5: Particles density distribution of the phase along the machine.

Cavity Tuning Method

The calibration of the cavity is based on the phase scan matching procedure [4] allowing to be less sensitive to phase errors due to cable length and hardware electronics. The quantity $\Delta\phi = (\phi_2-\phi_{2,\mathrm{off}})-(\phi_1-\phi_{1,\mathrm{off}})$ is matched to simu-

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lated one according to RF scheme shown Fig. 6. This approach makes also cavity tuning less sensitive to BPM position errors. Rebuncher, CH-DTL and spoke cavities are all tuned with this method.

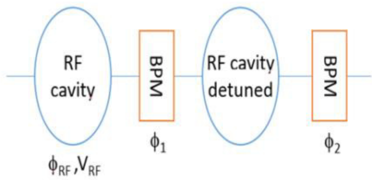

Figure 6: RF cavity scheme.

STATISTICAL STUDIES

2 different cases have been considered:

- The usual simulation without cavity tuning including phase and amplitude RF errors set respectively to 1° and 1%.
- The new simulation type including cavity tuning.

Both cases were performed with large scale simulations of linacs combining different random sets of errors. Correction scheme, element and diagnostics errors are also considered in each simulated machine including cavity tuning. The number of particles of each simulation is set to 1.10^6 and the Monte Carlo simulations are done with 1000 different linac configurations. This cumulative statistic representing $3x10^9$ particles allows to very accuracy characterize beam losses occurring in the structure

Usual Simulation (Errors 1°, 1%)

Considering no cavity tuning, errors are set as dynamic and mainly correspond to LLRF errors and thermal cable shifts. Figure 7 shows the particles leaving the longitudinal acceptance, the average beam losses representing 0.159 W.

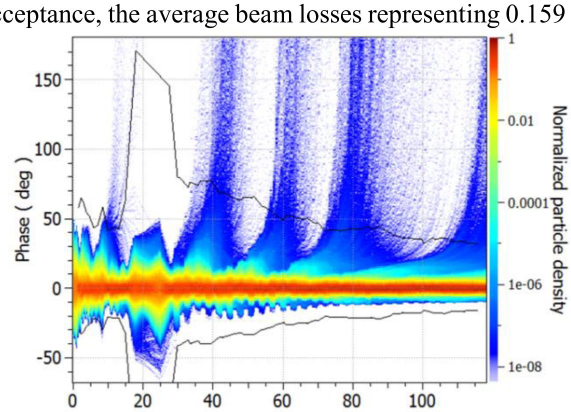

Figure 7: Superposition of the 1000 beam longitudinal densities (phase).

New Simulation Including Cavity Tuning

For all CH-DTL, Rebuncher and spoke cavities, we used 2 BPMs to measure the beam phase and tune the RF setting point. We didn't add extra diagnostics, using only BPM already present for controling the beam transverse position. For each of them, we considered a random error of position along the structure (see Table 1). This specific error has been increased from 0 to 1 mm in 5 steps.

Table 1: The Amplitudes of Cavity and BPM Errors

Error	Amplitude
RF field	± 20 %
RF phase	± 180°
BPM position	± 0 to 1 mm
BPM accuracy	± 0.2 mm

Figure 8 shows that even considering a huge error on the BPM position (1 mm), average of the total beam losses occurring in the structure stay always largely lower than the project requirement.

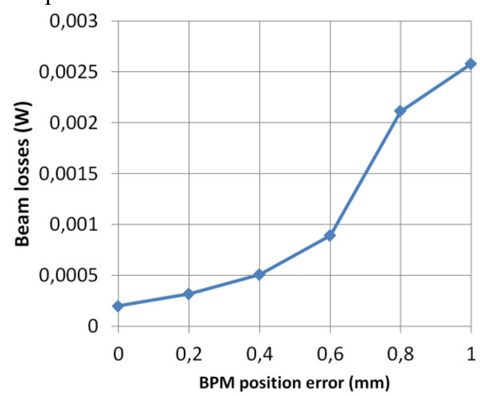

Figure 8: Average of the total beam power losses along the linac as a function of the BPM position error.

CONCLUSION

Don't be able to make a clear distinction between longitudinal static and dynamic errors, was a serious problem especially when the main losses are due to particle leaving the beam acceptance. This new development fixes this issue. Integrated in the TraceWin code, the community users can now applied to machine tuning a more coherent procedure including transverse and longitudinal aspects. This new feature allows to machine designer to specify to diagnostic team, realistic request on longitudinal diagnostic precision, such as the BPM position precision along the structure and to RF team requested precisions about LLRF, thermal cable shift and so one.

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