ON THE PERFORMANCE OF COMPUTER AUTOMATIC TUNING AT THE UNILAC

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Abstract

The Unilac is a multi-particle, variable energy linac. Automatic tuning procedures have been used in routine operation for many years. The algorithms were developed for transverse beam optimization at the linac and the transport lines in the experimental area. A successful application demands a thorough understanding of the machine, which results in a good computer modeling. It will be shown that linear treatment of the beam dynamics is normally sufficient, limitations for special sections of the accelerator will be discussed. Complementary, limitations in hardware, e.g. misalignment of components, tolerances in magnetic strengths and in beam diagnostics, affect the effectiveness of the procedures.

Introduction

The Unilac as a variable particle and variable energy accelerator requires computer aided tuning procedures to improve the efficiency of operation.

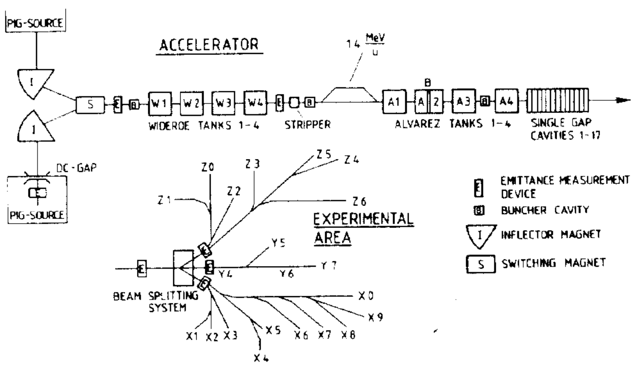

Fig. 1 Schematic diagram of the Unilac

Fig. 1 gives a schematic view of the Unilac. For transverse beam optimization the accelerator is divided in subsystems, each containing an emittance measurement device which delivers the input parameters for the fully automatic tuning code TSO[1]. This code matches the particle beam to a given acceptance of a successive accelerator tank or transport line by evaluation of the behaviour of a corresponding computer simulated beam. Then nominal quadrupole settings of the successive system lead to maximum transmission and to the desired beam quality. Each tuning section has to meet different requirements, e.g. mass separation in the injection channel, matching to the small and highly divergent acceptance of the Wideröe accelerator, adaption to the stripper device and postaccelerator acceptance or dispersive beam transport for an experiment station. To ensure the successful application, the beam behaviour has to be understood thoroughly. Studies considering higher order aberrations of bending magnets and quadrupoles, numerical integration of measured quadrupole field distributions, inaccuracies of emittance measurements and magnetic field strength as well as misalignments of transport elements have been made and supplemented by beam experiments. It turned out that the effectiveness and reproducibility of a computer automatic algorithm imposes stringent requirements on beam diagnostics, magnet field calibrations and beam line alignment in particular sections. Limitations result from using a simplifying linear treatment of the simulated beam in the operating code which in critical cases leads to unpermissible deviations from a complex beam simulation model. In the following the performance of the automatic tuning procedure will be discussed for selected sections of the Unilac. Particular problems and limitations will be pointed out.

Automatic tuning of the Unilac prestripper part

An emittance measurement device at the ion source terminal delivers the parameters to tune the beam for mass separation (Fig. 2). Reference input-, output-emittance and envelope are indicated by dotted lines. Measured input-emittance, optimized envelope and output-emittance are displayed in solid lines and are at the end of the section in accordance with the acceptance of the successive transport line or accelerator tank set to nominal values. In this case the procedure should perform simultaneously a reasonable particle transmission and the separation of isotopes up to lead, which means a horizontal waist at the separation slit positioned at the end of the envelope in fig. 2.

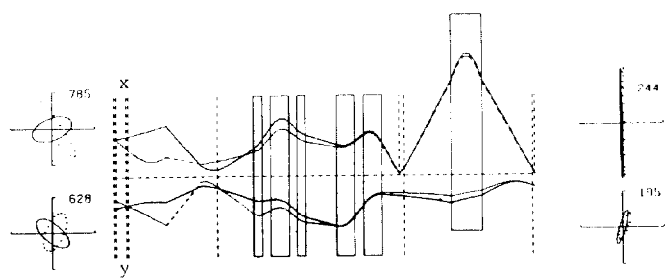

Fig. 2 Computer matched envelope for mass separation

The success of automatic tuning of this section can be affected by different reasons. Theoretically deviations arise between higher order and first order particle tracking but do not disturb the linear working procedure. Another effect is caused by the gaussian-like quadrupole field shapes. For instance, due to the geometry of the installed quadrupoles - aperture diameter 85 mm, iron length 115 mm - the normally used ion optical length calculated from the hard edged model has to be corrected from 130 mm to 156 mm.

Studies on the influence of hardware uncertainties have also been carried out. Emittance parameters have been varied within ± 20 %. Because of the wideband design of the injection beam line and its insensitivity to errors in emittance parameter values, the resolution of 1 mm in space and 5 mrad in angle of the emittance measurement at the ion source terminal is sufficient. Typical emittances at this point are in the range of 250 π mm mrad. Not negliable are tolerances in magnet field calibrations. Statistically distributed errors of field strength gradients of ~ 2 % in average disturb the mass separation at least for very heavy ions (Fig. 3) and also the emittance matching to the acceptance of the following section. On the other hand it was analyzed that systematical errors < 5 % have no substantial effect on the success of our tuning program. All these calculations have been carried out with the single particle tracking code PARMT-GSI.

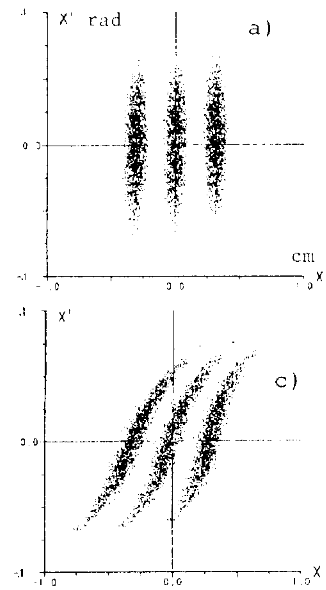

Fig. 3 Horizontal emittance of Pb isotopes at the mass separator slit
a) linear transformation
b) higher order transformation
c) magnet field errors of 2 % in average

Transport element misalignments have been introduced into the first order transport code MIRKO[2]. The influence on the mass separation is limited. Calculations with different statistical misalignments verified the preservation of the beam waist at the separation slit, but a deviation from the beam center line within the inflecting magnet. This effect increases downstream to the Wideröe accelerator. The model was supplemented by the introduction of statistical field gradient errors < 2 %. The combined influence on the output-emittance at the midplane of the first gap of Wideröe tank 1 is illustrated in Fig. 4.

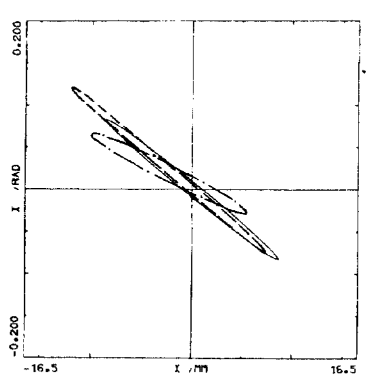

Fig. 4 Horizontal emittance at the end of the injector
——— without imperfections
– – – – with misalignments
—·—·- plus magnet field errors

The according acceptance of Wideröe tank 1 was determined by the PARMILA-GSI multiparticle code. Fig. 5a shows the acceptance for reference phase particles (dotted) and the acceptance of phase position ± 30 ° (solid). The effective acceptance is given by the

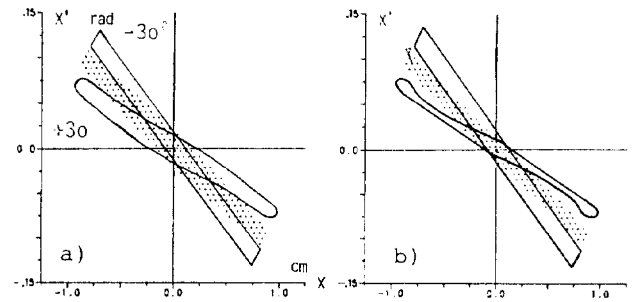

Fig. 5 Horizontal acceptance of the Wideröe Linac
a) without imperfections
b) with magnet field errors

cross-section and is in the order of the injected emittance. With the introduction of field gradient errors of 2 % in average the effective emittance area decreases strongly and can be slightly twisted (Fig. 5b). Fig. 4 and 5 give an impression of the matching sensitivity of the section located in front of the Wideröe structure to its acceptance.

The sum of model and machine imperfections leads to the following evaluation of the effectiveness of computer automatic tuning of the Unilac prestripper part.

Advantageous in the injection channel are: the very precise energy measurement[3], no proximity influence of multipletts in front of the switching magnet, and a reasonable magnet field strength calibration and control to ensure the reproducibility of calculated settings.

The tuning of the first part of the injector is particular critical. Due to the dispersive beam transport the acceptance of the spectrometer part is mainly determined by the aperture of the inflecting magnet. Measurements at the entrance slit of the mass separation system demonstrate distorted emittances caused by the ion source extractor and accelerator column abberations (Fig. 6). This can result in an emittance growth up to a factor of two and reduces the reserves in acceptance. The linear working TSO operating code can not take into account all these problems concerning ion optics of big emittances arising at the magnet spectrometer and its application occasionally results in particle transmission losses and in case of very heavy ions sometimes in insufficient mass separation. A manual correction of the transport element currents is then necessary in order to produce the desired physical beam parameters.

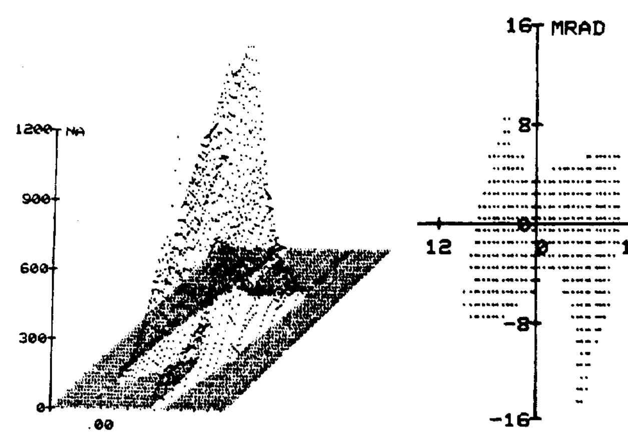

Fig. 6 Measured horizontal emittance at the entry of the inflecting magnet

The second matching section contains an emittance measurement device with the resolution of 1 mm and 1 mrad, precise enough for emittance values of 30-80 π mm mrad in front of the Wideröe structure. After taking into account proximity effects, which have caused errors in the effective length up to 5 % in the early Unilac operation, and eliminating magnet calibration errors, a success in the application of the TSO program to match the beam to the acceptance of the nominally adjusted Wideröe accelerator is ensured. Especially for light ions the situation is relaxed because it is possible to operate the Wideröe accelerator with increased transverse phase advance resulting in an extended acceptance area. Residual transmission losses caused by missteering are finally corrected by an automatic beam alignment program[1].

Automatic tuning of the Unilac poststripper part and experimental area beam lines

The conditions for automatic tuning of the Unilac poststripper and the experimental area beam transport lines differ from those of the prestripper. The acceptance to emittance ratio of about 10 permits a wideband computer controlled tuning, in particular the matching of the Wideröe output-emittance to the stripper orifice, the charge separation system and further downstream to the Alvarez tank acceptance. Slight deviations in magnet field calibrations and emittance measurements (resolution 1 mm and 1 mrad) are irrelevant and do not disturb the TSO procedure. For the operator remains only to carefully align the beam to center line.

This unproblematic tuning will be restricted by the planned time share operation of the poststripper accelerator[4]. For this mode the Alvarez innertank quadrupole settings will be kept constant whilst the settings of the intertank quadrupoles will be pulsed for individual matching of the different beam species to the acceptance of the next Alvarez tank. Therefore a reduction of the effective transverse Alvarez accpetance down to an acceptance to emittance ratio of 2 for maximum beam rigidity proportion of 1:4 will occur. Accelerator experiments simulating the future time share option have been carried out with the outcome that the residual reserve in acceptance is sufficient for reliable application of the TSO operating code. Moreover it clearly turned out that for time share operation of the poststripper accelerator a careful computer aided emittance matching is indispensable.

For the experimental area beam transport lines in general the same estimation of uncritical application of computer automatic tuning is valid. The difficulties here in particular cases concentrate on producing the desired beam quality and focusing on target. Magnet spectrometer experiments for example demand a high energy resolution in the range of 1×10^{-4} after a 90° beam deflection in order to define a beam with a small energy spread by a slit system. The remaining beam is transported achromatically through a successive 90° deflecting system to ensure a stable beam spot at the experimental set up Z1 (see Fig. 1).

To produce a dispersive beam transport the TSO algorithm has to ensure a theory conformable image of the beam emittance at the entrance of the dispersively adjusted deflecting system. With the PARMT-GSI program different hardware inaccuracies which can affect the energy resolution have been studied. Statistical and systematical magnet field strength tolerances have been introduced with the result that the errors must exceed 5 % to realize a relevant influence on the energy resolution (Fig. 7). Here again the precise Unilac energy measurement system is important since an error in energy is equivalent to magnet field errors. The experimental area emittance measurement devices have a resolution of 1 mm and 0.5 mrad. This was confirmed to be adequate for successful automatic tuning. Nevertheless the emittance orientation determined at the slit is very sensitive to input-emittance errors.

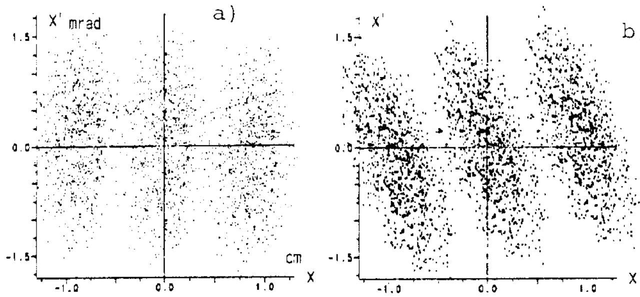

Fig. 7 Computed beams with energy deviations of $\pm 10^{-4}$; dispersively adjusted to experimental set up Z1
a) without imperfections
b) with statistical magnet field errors < 5 %

In many routine adjustments with the help of the TSO code the desired beam quality for the magnet spectrometer has been reliable generated. Requirements on beam properties for other experimental set ups are comparable to the above mentioned case or have less stringent conditions.

Demands to reduce halos or background radiation or to fullfil temporary requirements on beam properties can not be satisfied by the operating code. In these cases a manual fine tuning by the operator takes place.

Conclusions

The computer automatic tuning program TSO became a successful and time saving tool for routine operation of the Unilac. Two operators tune the machine in typically 6 hours for a new element. In general the linearly treated beam dynamics in the TSO code is sufficient. In some cases the procedure does not work accurately but nevertheless yields a coarse tuned beam which needs manual fine tuning. Conditions for successful use of the program are sophisticated modeling, accurate magnet field calibrations, beam diagnostics of sufficient resolution, and a data base precisely imaging the geometrical and physical properties of the accelerator. Even if time consuming and elaborate, this exact modeling of the accelerator seems to be more adequate and promising for the Unilac than an empirical model based upon the measured values of beam parameters. Especially for the planned time share operation the investments in accelerator development pay off in a fast and reproducible automatic beam handling.

References

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