ONLINE OPTIMISATION OF THE TRANSFER LINE FROM UNILAC TOWARDS SIS18 AT GSI USING A GENETIC AUTOTUNE ALGORITHM

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Abstract

Due to the complexity of GSI's accelerator facilities and it's upcoming expansion FAIR [1], various methods for optimising accelerator settings are currently being studied to increase efficiency and to minimise the need for manual intervention. Besides a necessary improvement of the accelerator models [2–5], a better reproducibility of settings and the development of feedback systems [6, 7], also heuristic methods are in the focus of the investigation [8–10]. This work presents the results, recently achieved in optimising the transfer line from UNILAC towards SIS18 (TK) using a genetic Autotune algorithm.

INTRODUCTION

The object of investigation was a 75 m long section of the transfer line from UNILAC to synchrotron SIS18 behind stripping and charge separation. Starting point was the beam transformer GTK3DT4, where the reference current I_0 for the optimization was measured. End point was the beam transformer GTK7DT3. The original intention was to optimize the entire beam transport up to the injection point of the SIS18, but the last two transformers GTK8DT7 and GTK9DT8 could not be used due to a technical defect.

The manual setup of the transfer line usually takes 1-2 hours. Since the SIS18 allows cycle times of < 1 s (in FAIR-booster mode 2.7 Hz operation is foreseen [1]) and different ion types and charge states can be requested from pulse to pulse, the transfer channel is designed for a corresponding repetition rate and all magnets can be pulsed with a frequency up to 10 Hz. The high repetition rate is an ideal condition for automatic optimisation procedures.

SIMULATION

A simulation was carried out to check the general feasibility and to find the optimal operating parameters for the genetic algorithm [11]. For the particle tracking the TK Lattice, measured and reconstructed by Y.El Hayek [12] (Fig. 1) was used. The standard deviation of fluctuations of the actual current of the power supplies were measured to 0.1% for quadrupoles and 0.04% for steerer magnets. These values were included in the simulation. The measuring accuracy of the transformers (0.3%) was also considered in order to represent the conditions of the real machine as close as possible. Several simulations were carried out to find the parameter set for the fastest possible convergence of the genetic algorithm. The fitness function to be minimized (1) represents the sum of the beam losses, measured via four consecutive beam transformers with the transmission $\tau_i = \frac{I_i}{I_0}$ weighted with a factor w^i. Compared to the fitness function which directly evaluates the beam losses, the slightly modified version converges more reliably.

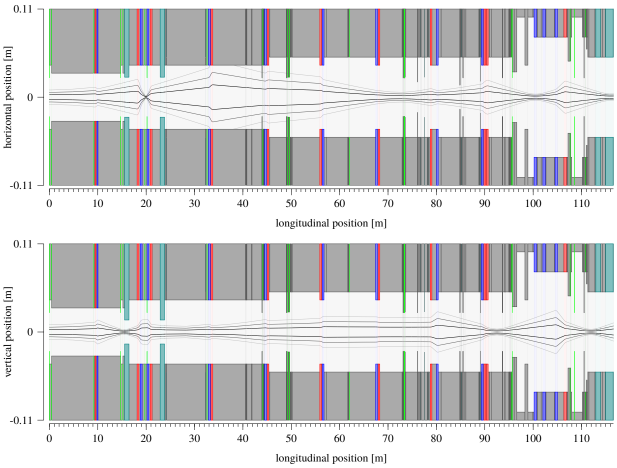

Figure 1: lattice of the transfer line (top = horizontal, bottom = vertical): blue elements are vertical focusing and red elements are horizontal focusing quadrupoles, cyan elements are bending dipoles.

$$F = \sum_{i=0}^{4} w^i (1 - \tau_i) \tag{1}$$

For this work, the same implementation of a genetic algorithm was used as in [13]. All parameters were scanned [14]. The algorithm is quite robust against hyperparameter changes, as can be seen from the example of mutation probability (Fig. 2). The optimal parameters for the given transfer line are listed in Table 1.

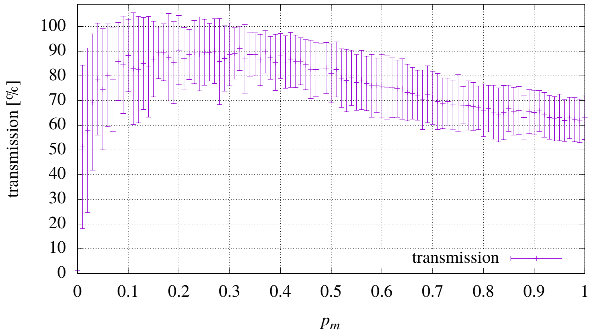

Figure 2: parameter scan of mutation probability p_m with respect to total transmission.

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Table 1: GA Parameters

name	parameter description	value
I	number of individuals	120
N_k	number of most performing individuals kept for next generation	1
σ_s	variance of individuals chosen for reproduction (0...best, 1..worst)	0.13
p_m	probability of each gene to mutate	0.38
p_r	probability of a gene to be replaced	0.0001
p_c	probability for crossing over at each gene	0.52
w	weight factor	2.7

With optimized parameters a convergence in 250 generations could be achieved. The same parameters were then used for the experiment with the real machine.

Although theoretical data exist for the transfer line, setting these values directly almost always leads to suboptimal settings with poor transmission which needs further manual optimization. Reasons for this are, among others, the use of different ion sources which produce different initial beam conditions, the use of different isotopes, different settings of the previous accelerator sections to optimize their imaging properties and the general but small variation of currents of the power supplies. A reproducibility of older setting data is also not given for these reasons. The model must therefore be better understood or alternatively in this work an autotune procedure was applied.

EXPERIMENT SETUP

For the experiment a completely stripped argon beam $^{40}\mathrm{Ar}^{18+}$ with an energy of 8.6 MeV/u was used. In order to prevent unnecessary activation, a pilot beam was used for the optimisation. The beam current was reduced to less than 100 µA on the reference transformer to additionally prevent the measuring range limits from being crossed and thus to avoid switching the beam transformers measuring range during the optimisation process.

For the beam time the high current source was in operation, which limited the repetition rate to $f_r = 1\,\mathrm{Hz}$. Unfortunately a promising run could not be completed due to a technical defect. Since the remaining experiment time was only $t = 40\,\mathrm{min}$ and because $t \cdot f_r = G \cdot I$, the final run had to be limited to $G = 20$ generations.

For the genetic algorithm the parameters from Table 1 were used and during the optimisation 2400 different settings were tested (corresponding to 20 generations) with one beam pulse each.

RESULTS

After the optimization time of 40 minutes, a total transmission of $T = 70\%$ could be achieved. Figure 3 shows the development of the transmission over the optimisation process at 4 consecutive beam transformers. The constantly limited transmission between reference transformer GTK3DT4 and GTK4DT3 suggests that the setup of the beam line before the reference transformer was not optimal and the resulting mismatch could not be corrected with the intermediate quadrupole doublet GTK4QD2. For the 54 m long section from GTK4DT3 to GTK7DT3 the final transmission was $T = 86\%$. For comparison: with manual tuning, values of up to 83% could be reached for this section within a similar optimisation time during the FAIR phase 0 physics run in 2020.

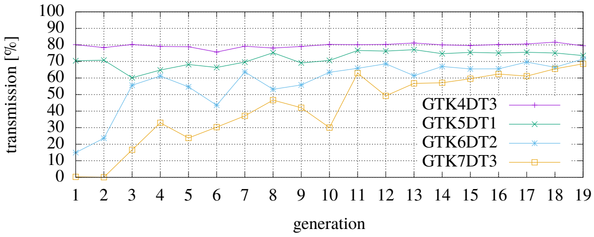


Figure 3: development of the transmission with regard to the reference transformer GTK3DT4.

Fitness value developed as in Figure 4. It is not yet visible that it is approaching a lower plateau, so it is to be expected that a longer optimization time would result in a further improvement.

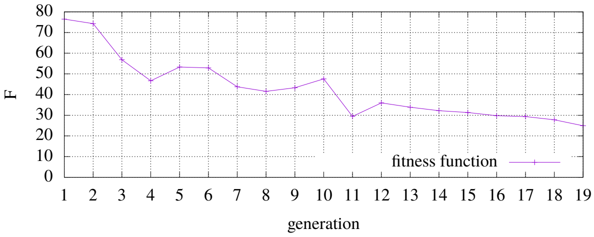


Figure 4: development of fitness value during the online optimization process.

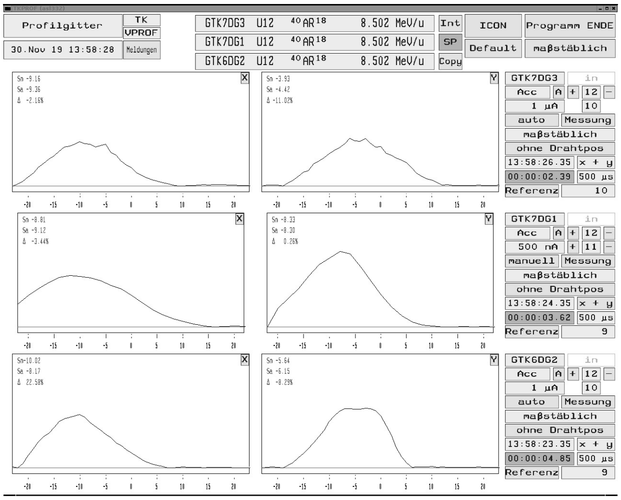
Low magnet excitations were not particularly preferred by the algorithm, so steerer magnets were not optimized to a low angle if this was not explicitely necessary to avoid losses. Therefore all profile grids show more offset than one would expect from a manual setup (Fig. 5).

CONCLUSION & OUTLOOK

The transfer channel is an ideal application for the autotune algorithm and should be further investigated and optimized. Both, setup time and transmission results are at least equivalent to manual tuning.

The entire channel should be optimized again in full length under normal operating conditions. For this purpose, an interruption protection must be implemented so that after interruptions it is not necessary to start the optimisation again from the beginning.

If the SIS18 fast beam transformer can be integrated into the optimization process, the injection efficiency could be



GTK7DG3 U12 $^{40}AR^{18}$ 8.502 MeV/u
GTK7DG1 U12 $^{40}AR^{18}$ 8.502 MeV/u
GTK6DG2 U12 $^{40}AR^{18}$ 8.502 MeV/u

GTK7DG3	in			
Acc	A	+	12	–
1 µA			10	
auto	Messung			
maβstäblich				
ohne Drahtpos				
13:58:26.35	x + y			
00:00:02.39	500 µs			
Referenz	10			
GTK7DG1	in			
Acc	A	+	12	–
500 nA		+	11	–
manuell	Messung			
maβstäblich				
ohne Drahtpos				
13:58:24.35	x + y			
00:00:03.62	500 µs			
Referenz	9			
GTK6DG2	in			
Acc	A	+	12	–
1 µA			10	
auto	Messung			
maβstäblich				
ohne Drahtpos				
13:58:23.35	x + y			
00:00:04.85	500 µs			
Referenz	9			

Figure 5: profile grid measurements of the best setting, left - the horizontal pane left and right - the vertical pane.

optimized directly. In this case the difficulty is to coordinate the synchronous access to parameters of the new FAIR settings management system [15], which is already in use from SIS18 downstream, and the legacy GSI control system used at UNILAC. If successful, further LSA top level parameters could be used for optimization and thus the complete injection process could be optimized online, as already suggested in [16].

A parallel simulation can eliminate total losses and thus reduce the number of cycles required. It has also been suggested that the BOBYQA algorithm [17] instead of a genetic algorithm can lead to a slightly faster convergence [18].

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