

# DATABASE-DRIVEN STATUS ANALYSIS IN BEAM OPERATION AT THE HEIDELBERG ION THERAPY CENTER

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## Abstract

The HIT (Heidelberg Ion Therapy) center is the first dedicated European accelerator facility for cancer therapy using both carbon ions and protons, located at the university hospital in Heidelberg. It provides three treatment rooms, two with fixed beam exit (operational since Nov. 2009 and Sept. 2010, respectively), and the first gantry worldwide where the beam exit can be rotated by 360 degrees, currently under commissioning.

HIT uses a PC-based proprietary software system for accelerator controls with an Oracle database for storing device parameters, beam history, error logging etc. Since medical treatment of humans requires a high level of quality assurance, a detailed analysis of beam quality and error logs is needed. We wrote a series of database applications using Python to perform these tasks automatically and create daily reports on beam statistics and parameters, machine status and errors occurred. Additionally, some graphical applications on top of the commercial control system help the scientists and operators in the beam commissioning of the new therapy treatment rooms and the gantry. We will present these applications and show how they are used at HIT.

## INTRODUCTION

The HIT accelerator setup as shown in Fig. 1 consists of

- two ion sources, currently used for producing carbon and proton ions (a third ion source is to be installed soon)
- a linac accelerating the ions to 7 MeV/u,
- a synchrotron used to accelerate the ions to their final energy as defined by the patient-specific treatment plan, and
- four high energy beam transport lines providing the beam to the horizontal treatment rooms, the rotatable gantry or the additional station dedicated to quality assurance (QA), research and development.

Cancer treatment with different ion types and of different patients in parallel requires a multiplexed beam operation with the possibility to switch the ion source and beam destination from pulse to pulse, every source/destination combination identified by a virtual accelerator number. Beam parameters can be chosen from a matrix of 255 energy values, up to 6 focus sizes and up to 15 different intensity val-

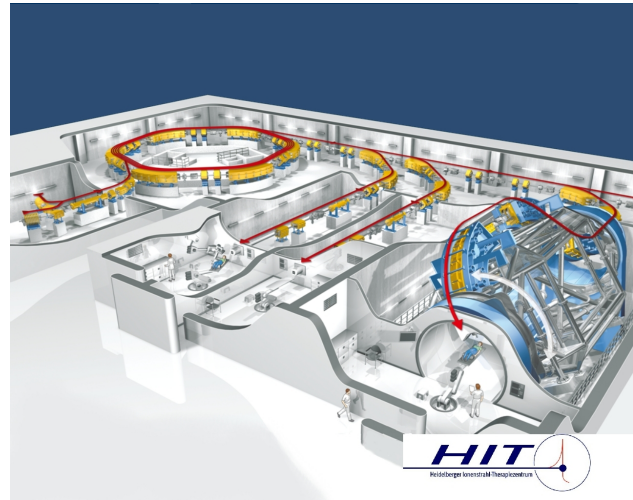


Figure 1: Overview of the HIT accelerator complex. (The QA station is not shown.)

ues, denoted as MEFI parameters. For commissioning and quality assurance, the beam is requested by the Accelerator Control System (ACS) directly, while in therapy mode the Therapy Control System (TCS) requests the beam characteristics determined by the treatment plan via a communication interface to the ACS.

HIT uses an accelerator control system built by a German company for automation and process control hard- and software [1]. It runs on Windows servers, using Oracle 9i as database backend. An upgrade to Oracle 11g is planned for the end of this year. While changes to the GUIs of the control system require invention by the supplier, we can easily access the tablespace used for accelerator controls in the Oracle database. Thus, we were able to develop database applications for various tasks in beam analysis and machine commissioning.

## APPLICATION ENVIRONMENT

For a fast development of database applications that may easily be deployed on different systems (Windows for client PCs in the accelerator control room, Linux for a server that is mainly used for the web based electronic logbook [2]), we decided for Python 2.6 [3] as a cross platform OO scripting language. Python provides a variety of builtin and 3<sup>rd</sup> party modules, including an Oracle module [4] compliant to the Python Database API 2.0. Table 1

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Table 1: List of used Python modules

Module	Purpose
cx_Oracle	DB-API 2.0 compliant Python wrapper for Oracle client libraries
csv	reading and writing comma separated values
struct	binary I/O
Datetime	providing date/time funtions
wxPython 2.8	cross platform GUI library

lists the most important Python modules used for our applications.

Since the creation of many data plots is needed both in beam analysis and commissioning, we use Gnuplot 4.4 as graphical utility that can be used in batch mode to produce plots from a list of plot commands automatically created by a script.

While the applications used for commissioning are realized as graphical applications on Windows client PCs using the wxPython wrapper for the C++ wxWidgets library [5], the apps for beam analysis exist either as Windows GUI for interactive analysis tasks or as command line scripts that are run by the cron demon on the Linux elog server to create automatic reports on beam performance.

## DATABASE TABLES

The accelerator control system stores any beam cycle with its attributes in a database table:

- Unique cycle id as primary key,
- start and end time of cycle, and
- foreign keys to other tables, like beam mode, cycle status and MEFI combination.

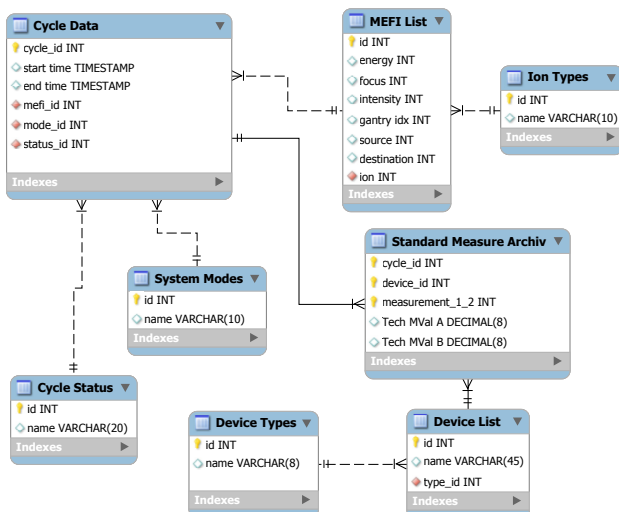


Figure 2: Simplified ER diagram of database tables.

Table 2: Analysis example: used beam request modes

	Cycles: Beam Modes				
	All	Carbon		Protons	
	Cycles	Cycles	Particles	Cycles	Particles
Total	3744	3094	$1.36 \times 10^{11}$	650	$1.53 \times 10^{12}$
TCS	2369	1778	$3.43 \times 10^{10}$	591	$1.47 \times 10^{12}$
ACS/Exp	1257	1257	$1.01 \times 10^{11}$	0	$0.00 \times 10^{00}$
ACS/QS	118	59	$1.47 \times 10^{09}$	59	$5.87 \times 10^{10}$

Measured values—like beam position and size on grids or currents of power supplies—are stored in a different table using the combination of cycle id, device id and measurement index (since some devices are measured twice per cycle) as primary key.

A simplified of the database tables used for storing cycle parameters and measured values is shown in Fig. 2.

## BEAM ANALYSIS TOOLS

As mentioned before, reports on beam performance are created by a Linux cron job, both on daily and weekly intervall. The cycle data for the time intervall of interest are read from the database and are analyzed by the following criteria:

- Number of failed cycles with analysis of error messages,
- origin of beam request: Therapy Control System (therapy) or Accelerator Control System (technical),
- ion types and destinations of beams,
- distribution of MEFI parameters in therapy mode: energy, focus and intensity.

We use HTML and  $\text{\LaTeX}$  as output formats, the former for a quick overview on beam performance within the electronic logbook, the latter for printed reports. Additionally, all beam parameters are archived as comma separated values since the maximum storage time in database is about six weeks. Thus, a long term analysis (e. g., the number of particles per year has to be checked against the limit in the permission for operation) is possible. Table 2 gives an example for the automatic analysis of the system modes that requested the beam during a 24 h period, while Fig. 3 shows the chronological distribution of virtual accelerators (i. e. combinations of source and destination) during the same period.

## TOOLS FOR COMMISSIONING

While patient treatment at a horizontal station started in 2009, the rotatable gantry is still under commissioning [6]. The raster scan technology used at the treatment stations requires a fixed beam position and focus size for all combinations of beam parameters: energy ( $E$ ), focus ( $F$ ), intensity ( $I$ ) and in the case of the gantry also the rotation angle ( $G$ ).

During commissioning, the beam is optimized for a subset of  $E$ ,  $F$ ,  $I$  and  $G$  combinations that are used as nodes

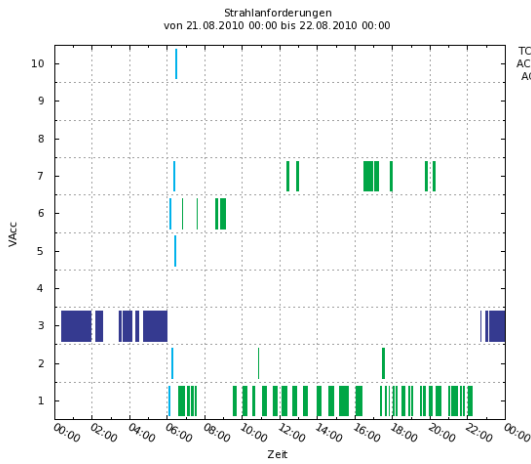


Figure 3: Chronological analysis of cycles. Virtual Accelerators (VAcc) denote a unique pair of ion source and beam destination.

for an interpolation of the full  $E \times F \times I \times G$  MEFI space. The quality of interpolation is checked by running various beam sequences and measuring beam position and size on a fluorescent target. In the past, these checks involved a lot of manual work by the operator, i. e. exporting the data sets as CSV file and importing them into a spreadsheet to get a comparison to the reference values. With our new database applications, we read both the measured values for beam center and FWHM of the beam size and the reference values from the database and directly show the result in a graphical window as table (see Fig. 4) or plot. The GUI supports plotting slices from the  $E \times G$  data set, i. e.  $E$  on x-axis for a chosen gantry angle  $G$  or vice versa. (Fortunately, the set values for the magnets in the gantry don't depend on  $I$ .)

The GUI was developed with the aim of supporting the usual tasks performed by the accelerator scientist during

	E	F	I	G	H	Y	FWHM x	Abw. in %	FWHM y	Abw. in %	FWHM z
#625172	255	1	10	19   180°	-2.998	-1.296	3.813	-4.820	3.941	-6.081	6.370
#625178	1	1	10	19   180°	-0.518	0.280	17.783	-14.262	14.636	-6.928	6.280
#625179	255	1	10	19   180°	-2.995	-1.412	3.263	-3.756	3.503	-1.878	3.570
#625180	1	1	10	19   180°	-0.275	0.418	13.269	-13.313	14.596	-7.818	16.980
#625181	1	3	10	19   180°	-0.209	-0.301	12.807	-7.962	16.038	-15.255	13.915
#625182	1	2	10	19   180°	-0.273	-0.146	11.094	-6.001	13.229	-17.446	11.770
#625183	1	1	10	19   180°	-0.010	-0.560	10.316	-5.100	10.799	-4.588	10.290
#625184	30	4	10	19   180°	-0.313	0.361	12.795	-6.763	14.703	-7.481	13.660
#625185	30	3	10	19   180°	-0.282	0.219	10.649	-6.622	14.233	-27.468	11.195
#625186	30	2	10	19   180°	0.050	-0.249	8.257	-6.168	11.023	-25.260	8.800
#625187	30	1	10	19   180°	0.200	-0.146	6.662	-5.022	7.946	-7.271	7.028
#625188	60	4	10	19   180°	-0.563	0.138	13.446	-7.708	12.803	-6.658	12.720
#625189	60	3	10	19   180°	-0.441	0.006	10.312	-1.998	10.788	-8.923	10.120
#625190	60	2	10	19   180°	-0.284	-0.136	6.962	-7.320	9.527	-13.982	7.480
#625191	60	1	10	19   180°	0.182	-0.410	5.452	-0.030	6.173	-10.932	5.925
#625192	90	4	10	19   180°	-1.104	-0.469	10.792	-3.889	14.271	-16.594	12.240
#625193	90	3	10	19   180°	-1.191	-0.491	8.441	-12.470	11.103	-14.935	9.660
#625194	90	2	10	19   180°	-1.007	-0.611	6.296	-6.288	8.528	-23.058	6.930
#625195	90	1	10	19   180°	-0.603	-0.264	4.423	-4.898	5.479	-17.887	4.820
#625196	120	4	10	19   180°	0.694	0.200	11.037	-0.937	14.706	-21.335	12.120
#625197	120	3	10	19   180°	0.686	0.208	8.461	-8.837	11.439	-21.194	9.420
#625198	120	2	10	19   180°	0.611	-0.074	6.228	-26.628	6.051	-11.978	6.600
#625199	120	1	10	19   180°	0.611	-0.388	4.191	-6.888	5.510	-29.362	4.410
#625200	150	4	10	19   180°	-0.161	-0.278	11.967	-0.026	14.262	-19.988	12.000
#625201	150	3	10	19   180°	-0.388	-0.293	8.872	-4.797	10.807	-16.015	9.315
#625202	150	2	10	19   180°	-0.158	-0.294	6.763	-5.048	8.886	-7.695	6.360

Figure 4: Measured data set: Table view, colors denoting the quality of beam center and focus size, respectively.

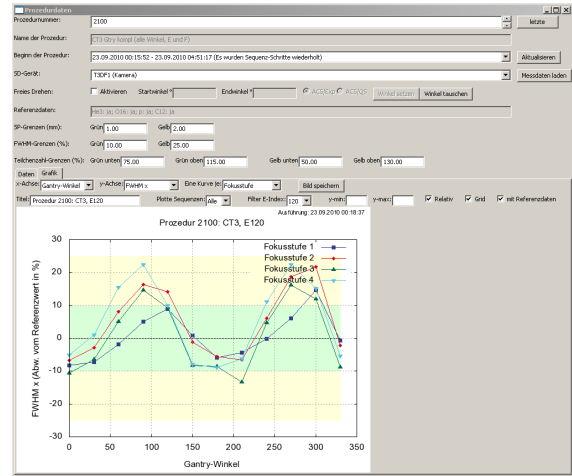


Figure 5: Relative deviation of horizontal beam size from reference value as a function of gantry angle, where a slice of the data set with energy index 120 is plotted.

commissioning. He can load the data sets from the sequence that was run most recently by a single click and easily chose the device of interest from a list of beam instrumentation devices like the fluorescent target or grids and ionization chambers within the beamlines that were active during the sequence. The standard limits for categorizing the beam quality by colors are read from a configuration file, but these limits may also be changed within the GUI. Plots may be exported as PNG files what is heavily used for adding plot to reports on the outcome of commissioning shifts. For further analysis, data sets can be exported as CSV files.

Figure 5 shows the relative deviation of horizontal beam size from the reference value as a function of gantry angle for a fixed  $E$  index.

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