THE HIGH ENERGY BEAM TRANSPORT SYSTEM FOR FAIR*

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Abstract

The High Energy Beam Transport (HEBT) System of the **F**acility for **A**ntiproton and **I**on **R**esearch (FAIR) [1], with a total length of more than 2350 m, forms a complex system connecting seven accelerator- and storage rings, the experiment caves, beam dumps, stripping stations, the antiproton target and the Super Fragment Separator (Super-FRS). The variety of beams to be transported is considerable, ranging from slow extracted beams with long spills of up to 100 s to short intense bunches with lengths of a few nanoseconds and momentum spreads of up to ±1 %. The range of beam intensity covers more than six orders of magnitude.

The SIS100/300 synchrotrons are located under ground, 13.5 m below SIS18 (the existing 18 Tm Heavy Ion Synchrotron) while the rest of the facility is essentially on ground level necessitating a 3-dimensional layout of the beam line system.

In order to minimize the technical complexity, most of the beam transport elements are normal conducting magnets. However, the 300 Tm beam transport line has to be built from superconducting magnets.

Due to the large variety of beam parameters, a careful planning of the beam diagnostics system is important. The paper summarizes the design fundamentals and the current status of the system design.

GENERAL REQUIREMENTS

FAIR will be built east of the present GSI facilities, see Figure 1. The extension of the building ground was fixed several years ago. Since this time many parts of FAIR have undergone various optimization processes and the arrangement of building blocks on site was changed several times. Finally the restricted space turned out to be a major challenge.

The building site is crossed by a public promenade. So far, north of the promenade only underground buildings are allowed to be built. The depth of the synchrotron tunnel was determined from shielding requirements. The tunnel has three equally distributed supply buildings along its circumference. At least one third of the circumference must be located south of the promenade.

The superconducting 300 Tm beam transport line from SIS300 to the nuclear collisions cave (CBM) and to the machine setting dump is guided at an intermediate level under ground at -6 m relative to SIS18.

To save building costs (e.g. the material from the excavation of the ring tunnel will be used for shielding) all other parts of FAIR are installed on ground level. In the south, the RESR encloses the CR, which is located on the same level as SIS18. However, the RESR is placed 1.2 m higher than the CR in order to separate the respective vacuum systems. The NESR and the FLAIR complex have the same vertical position as the RESR. All other parts are on the same level as SIS18.

All beams for the FAIR facility will be pre-accelerated in SIS18. It is regarded as starting point for the design of the new FAIR HEBT system. As SIS18 will be used continuously until FAIR is constructed, the existing extraction system of SIS18 is conserved.

LAYOUT PRINCIPLES

Magnets

Several magnet types used for the HEBT system are taken from other parts of the FAIR facility (e.g. CR) or from the existing 18 Tm beam transport lines of GSI. In case slightly different bending angle were needed, equal cross sections of the dipoles were used. The standard bending angle of the 100 Tm normal conducting dipoles is 3.33° (as in SIS100) with a maximum magnetic field of 1.8 T. At the 100 Tm beam transport line junctions H-type dipoles and figure-of-eight quadrupoles are needed.

Acceptance

The beams with the maximum emittance, which are generally the fast extracted beams at minimum magnetic rigidity, determine the ion optical layout. It has been decided that the acceptance of the beam transport lines shall be two times larger than the maximum emittance to be transported. Thereby, the HEBT system provides enough tolerance for misalignment and steering or gradient errors in the quadrupoles. The optical settings are the same for all beams. Therefore, for beams with higher rigidity or slow extracted beams the acceptance or tolerance is higher.

The momentum width of compressed beams from SIS100 will be up to ±1 %. Therefore, the dispersion trajectories have to be taken into account for the determination of the acceptance. At the exit of all beam transport lines, where fast extracted beams are transported the dispersion is compensated in first order.

Ion Optical Layout

For the ion optical layout the GSI ion optics program MIRKO [2] has been used. The results were checked with TRANSPORT [3]. TRANSPORT was also used to calculate the effect of space charge for compressed bunches. It was shown that at lowest extraction rigidity space charge leads to an increase in emittance of about 50 %. At highest rigidities there is a mere 10 % effect. The defocusing due to space charge can not be compensated, since the transverse density of the beam

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varies along the bunch. Its impact can be minimized by avoiding sharp intermediate beam waists.

To a large extend F0D0 focusing has been used. This focusing scheme requires the lowest quadrupole gradients.

Dispersion is allowed section wise with ideally two or more quadrupoles in between for the control of transverse focusing.

Beam Diagnostics Equipment

Due to the large variety of beam species and intensities as well as the different demands for fast and slow extraction, various beam diagnostics devices are needed, see Table 1. Many of the beam transport lines have multi-purpose use and must be equipped with diagnostics installations for the full range of beams.

Table 1: Beam diagnostics devices used in the FAIR HEBT system [4].

Device	Measured Parameter	Intercept./ non-intercept.	Extr.	Remark
Resonant Transformer (RT)	beam current	non-intercept.	fast	
Fast Current Transformer (FCT)	bunch charge/ time structure	non-intercept.	fast	
Particle Detector Combination (PDC)	current	intercepting	slow	low intensities
Cryogenic Current Comparator (CCC)	current	non-intercept.	slow	high intensities
Beam Position Monitor (BPM)	centre-of-mass	non-intercept.	fast	position
SEM-Grid (PG)	transverse profile	intercepting	fast	profile & position
Scintillation Screen (SCR)	transverse profile	intercepting	fast & slow	profile & position
Multi-Wire Proportional Chamber (MWPC)	transverse profile	intercepting	slow	profile & position
Beam Induced Fluorescence (BIF)/ Ionization Profile Monitor (IPM)	transverse profile	non-intercept.	fast & slow	profile & position, high intensities
Beam Loss Monitor (BLM)	beam loss	non-intercept.	fast & slow	

DESCRIPTION OF THE ION OPTICAL LAYOUT

Beam Transport Lines

Instead of a single beam transport line numerous transport lines and shortcuts are needed. E.g. the Super-FRS is alternatively served by SIS18, SIS100 and SIS300. Figure 2 shows a schematic overview of all connections which are planned.

Starting point for the new beam transport system is a bipolar switching dipole behind the extraction from SIS18. The 96° bend acts also as a charge state separator for a stripper foil which is included in its first part. Behind point B, the beam is transported down to the underground ring tunnel level. The beam from SIS18 is injected into SIS100 horizontally from the outside. Due to the doublet structure of SIS100 horizontal injection requires the lowest kicker strength and avoids interference of the injection beam line with SIS300. SIS300 is planned to be installed 1.4 m above SIS100 within the same ring tunnel.

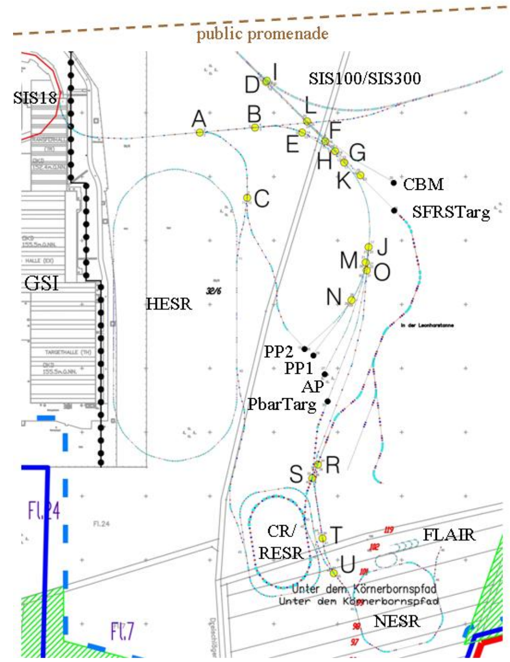

Figure 1: Top view of the beam line topology of FAIR (Status: Spring 2007).

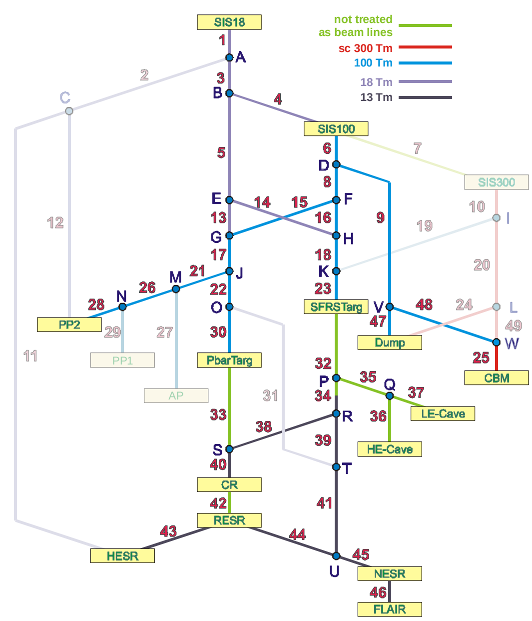

Figure 2: Beam line connection scheme. The blue dots indicate beam dividers/combiners. Sections not belonging to the start version are shown in a lighter shade.

Extraction from SIS100/300 is in vertical direction and situated at the same position in the ring tunnel. The vertical extraction allows the shortest transition from the tunnel level to the ground level. Even then the total length of the vertical transition section with a maximum intermediate slope of 10° and an intermediate zero crossing of the vertical dispersion is almost 120 m (see Figure 3). This is partly a consequence of the vertical extraction itself: The extracted beam from SIS100 has to bypass SIS300 which requires a 16 m drift where no magnets can be placed.

At an intermediate level underground a switching system is used in the SIS100 and the SIS300 beam transport line to direct the beam to the beam dump and the CBM cave. The main beam transport lines continue up to the SIS18 level and serve the Super-FRS target (and in the case of the SIS100 beam all other experiment caves and the antiproton target). The 100 Tm and 300 Tm beam lines are guided in parallel with a vertical offset of 1.4 m. Only in the vertical transfer system the distance growth to 2 m.

The ring branch of the Super-FRS ends with an angle of 66° relative to the Super-FRS's initial direction. From the ring branch as well as from the antiproton separator secondary beams are transported via the same injection channel to the CR. Therefore, the main 100 Tm beam transport line to the antiproton production target must also have a total bend of 66°. However, the Super-FRS has a maximum magnetic rigidity of 20 Tm only, which means, that it is the extension of the 100 Tm bend which determines the overall extension of FAIR. In order to make the bend compact, dispersion is non zero. Single dipoles in all experiment lines bring the dispersion back to zero in front of the respective target focusing system.

This 100 Tm bend is also used for the transport of 18 Tm beams from SIS18 to the AP-cave and for 13 Tm beams to the NESR. To save system costs, a general design criterion was to use beam transport lines for different connections wherever possible. However, due to the demands of parallel operation it must be possible to ramp most of the transport lines to match the different conditions from shot to shot.

Beam Diagnostics System

The beam diagnostics system delivers all relevant beam parameters needed for a proper adjustment and operation of the beam transport lines. Behind each synchrotron and storage ring, at the end of each connecting section, as well as in front of the final destinations, beam currents, beam profiles and beam positions are measured, see Figure 3. To allow a clear diagnosis of the entry beam parameters and to correct the beam in position and angle at the final destination, at the beginning and at the end of a beam transport line the bunch profile (at fast extraction) is determined and additional position measurements are foreseen. The arrangement of further position- and profile monitors in the sections along the beam transport lines is determined by ion-optical criteria, e.g. the requirements for beam steering (effective drift length between steerer magnet and monitor). Beam steering is performed stepwise in the beam transport lines. The correct focusing and the beam envelope are checked exemplarily with the profile monitors distributed along the transport lines. The transverse phase space is determined by means of profile monitors placed in dispersion-free sections.

For fast and slow extraction the alignment of the beam onto the central axis of the beam transport lines is enabled by using a beam with medium intensity. Therefore, most of the diagnostics devices are based on intercepting technologies. However, the amount of non-intercepting devices for online position measurements is not sufficient to enable an automatic beam steering.

For the high intensity operation, additional non-destructive devices are foreseen at a few selected positions to assure an online monitoring of the beam current (for slow extraction only), the beam profile and its position.

The design concept for the beam diagnostics system does not reflect machine protection issues yet.

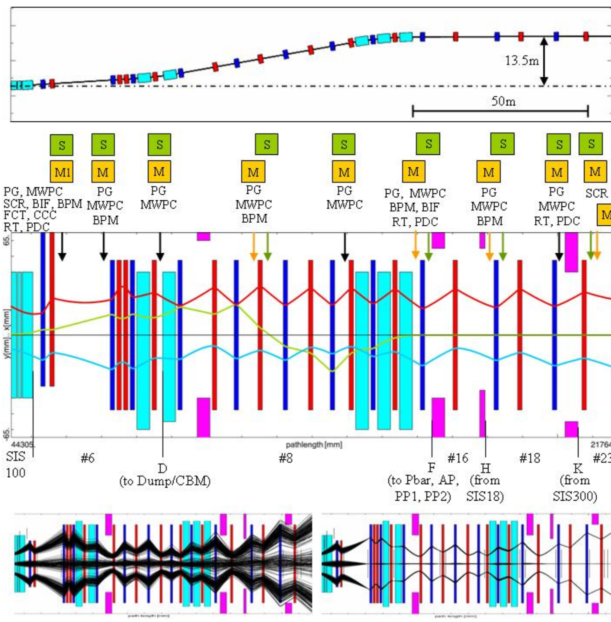

Figure 3: Beam line from SIS100 to the Super-FRS (top plot – side view). The emittances are 25/10 mm*mrad, the momentum offset is 1 %. Red/dark blue squares indicate horizontally focusing/defocusing quadrupoles, cyan squares dipoles, green squares steerer magnets, yellow squares monitor (abbreviations see Table 1) positions, magenta squares the aperture limitations due to switched off divider/combiner dipoles. The blue/red line shows the horizontal/vertical beam envelope, the green line the vertical dispersion trajectory. The bottom plots show the uncorrected and corrected beam center with envelope in the vertical plane taking into account misalignment (quadrupoles and dipoles) and field errors (dipoles).

REFERENCES

[1] FAIR Baseline Technical Report (FBTR), GSI 2006.

[2] B. Franczak, MIRKO – An Interactive Program for Beam Lines and Synchrotrons, Proc. of the Europhysics Conf. on Computing in Accelerator Design and Operation, Berlin 1983.

[3] U. Rohrer, PSI Graphic Transport Framework, based on a CERN-SLAC-FERMILAB version by K.L. Brown et al.

[4] P. Forck et al., Proc. EPAC2006, Edinburgh, p 1016.