INTRODUCTION

The long-running components already in procurement for SIS100 (e.g. dipole, quadrupoles, RF, acceleration systems, see fig. 1 and 2) are related to the machine’s safety. Safety topics must be distinguished between machine safety (i.e. protecting the machine from destruction by the high intensity ion beam or electrical / pressure related hazards) and personnel safety topics (not shown here).

Errors introduced by the machine operator personnel, setting value generation software, beam instabilities (and failures not found by analysis) are proposed to be dealt by the use of a low-intensity pilot beam after change of crucial settings and the beam loss monitoring system. The latter will help to find obstacles like forgotten objects in the beam (see fig. 3), too.

A failure mode and effects analysis on the system level (S-PMEA) and assessment acc. to DIN EN 50169 - EN ISO 13849 has been done (see tab. 2). This leads to a SIL category necessary for the safety functions.

All systems are characterized by their MTTF, the probability to detect the failure and MTTR. Later, when details on their architecture do exist, they are scrutinized on a part level using FIT (failures in 10^6 h) values. Finally, for all subsystems leading to the failure, PFH and DCanv values are calculated.

MACHINE PROTECTION

The destruction capability of the ion beam is low, see tab. 1. Even by strong focusing, one could not reach an energy density large enough to melt steel (E_{peak} = 1.2 kJ/nm) necessary spot radius less than 0.2 mm. Assuming single device errors, the spot size is not achievable with the synchrotron’s focusing structure and beam size.

Therefore, only the first three of the following failure effects have been identified to be potentially dangerous for the machine already at their first occurrence:

1. Queen of magnets/busbars,

2. Helium supply line pressure rise, leakage or rupture,

3. Horizontal “squiralling” of the beam towards the outside of the synchrotron and

4. Fouling of the beam onto a perpendicular thin wall (e.g. vacuum chamber).

Further (non-destructive) events have been found to be the effect of other failures:

• Beam blow up (which will hit the halo collimators),

• Horizontal closed orbit distortion to the inside of the synchrotron (beam hits cryocatchers) and

• Vertical beam loss (beam hits halo collimators).

The halo collimators and cryocatchers are designed to withstand a small impact of a full ion or proton beam, so these are not critical. The failures which will lead to beam loss in a short amount of time (us, ms) or mitmssion blow up, therefore, an emergency dump will be initiated by a fast fallasate optical signal. For failures which are not critical, a simple interlock will be generated to stop further injections into the synchrotron.

Emergency dump

To use the emergency dump during the whole cycle of SIS100, the extraction kickers are ramped, bipolar devices. A kick upwards extracts the beam to the experiments, a kick downwards will dump the beam below the magnetic septum, see fig. 4. Failure of one extraction/emergency dump kicker will still direct the beam onto the emergency dump. The remaining dose of beam fragments will not lead to a queen of the following quadrupoles, see fig. 5.

The emergency dump is composed of a 20 cm carbon block, followed by up to 2 m massive tungsten. To smear out the bragg peak in the absorber material, the front surface of the block is inclined by 20°, which will limit the peak temperature in the absorber.

MACHINE AVAILABILITY

Taking into account the currently analyzed probabilities of failures (i.e. safe and dangerous failures), an availability of SIS100 has been estimated. Assuming a interruption time of 10 min after quench events and 2 min after emergency dump events, the yearly overall availability would be 4 x 537 h out of 6 000 h (73 %).

Table 2: Part of the S-PMEA for SIS100 (failures and effect on the beam).

<table>
<thead>
<tr>
<th>Component</th>
<th>FIT / 10^6 h</th>
<th>DCanv %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage taps</td>
<td>2.3x10^5</td>
<td>90</td>
</tr>
<tr>
<td>Quench detector</td>
<td>3.4x10^4</td>
<td>70</td>
</tr>
<tr>
<td>Overall Q/D system</td>
<td>5.3 x 10^4</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 3: Dipole Q/D analysis results.

Quench detection and protection

Analysis shows that the Q/D system must fulfill the SIL3 criteria. The voltage across two symmetric s.c. magnet coil pairs is measured by a redundant read out measurement bridge (see fig. 9). When a bridge voltage threshold of 100 mV is reached for 10 ms, a false alarm signal is sent to start the emergency beam dump. Afterwards, the magnet current dump resistor is switched on. Table 3 shows the result of the analysis acc. to EN ISO 13849 for a single dipole (the values for the other magnets differ only slightly).

Horizontal beam loss onto electrostatic septum

The electromagnetric septum for slow extraction (see fig. 10) is situated radially at the outside of the synchrotron and defines its acceptance. Therefore, its wires are prone to damage by slow, spiraling impact of the full beam (which already happened once at SIS18). This will produce a large downtime of the accelerator which has to be avoided. Analysis show that a SIL3 category has to be fulfilled and the following failures will lead to this effect:

• Main dipole or power converter (PC) failures
• Horizontal steerer quench or PC failures
• Chromaticity sextupole quench or PC failures
• Octupole quench or PC failures
• Resonance sextupole failures
• Acceleration RF (cavity or PC) failures

An emergency dump will be initiated whenever a failure is detected directly by the devices themselves or indirectly by the beam loss monitoring system. As one of the driving factors, the estimated dipole power converter FIT values are shown as an example in tab. 4 (the values for the other power converters are similar).