MICE Beam Line Construction

Introduction

The MICE beam line is being built from existing magnets obtained from RAL and PSI. The availability of magnets is restricted. Three type I dipoles are available, of which two are needed in the MICE muon beam line design. Quadrupole magnets of three types are available although only two types have been chosen based on aperture considerations (see table). These magnets were previously used on beam lines at NIMROD and date from the '50s and '60s. A superconducting magnet previously used in the μE4 beam line at PSI has also been included in the design. The physical magnet characteristics are given in table 1. Further information is available on the web.

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Aperture</th>
<th>Physical Length</th>
<th>Typ. Max required (and limit) gradient or field</th>
<th>Number needed/available</th>
<th>I max (max supply)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q type-IV</td>
<td>20 cm Ø</td>
<td>110 cm</td>
<td>1.6 (10) T/m</td>
<td>3/3</td>
<td>160 (200)</td>
<td></td>
</tr>
<tr>
<td>Q type-35</td>
<td>34 cm Ø</td>
<td>117 cm</td>
<td>2 (8) T/m</td>
<td>6/7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D type-I 4” gap</td>
<td>H : 66</td>
<td>140 cm</td>
<td>(1.7)¹ T</td>
<td>2/3</td>
<td></td>
<td>D1/2: 415/140 (200/500) Field plots</td>
</tr>
<tr>
<td>D type-I 6” gap</td>
<td>H : 66</td>
<td></td>
<td>1.5 (1.47)¹ T</td>
<td></td>
<td></td>
<td>D1 field is up to 1.7 T D2 field is up to 0.5 T</td>
</tr>
<tr>
<td>D type-I 8” gap</td>
<td>H : 66</td>
<td></td>
<td>0.4 (1.25)¹ T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decay Solenoid</td>
<td>11 cm Ø</td>
<td></td>
<td>5 (5) T</td>
<td>1/1</td>
<td></td>
<td>Supply part of solenoid kit from PSI</td>
</tr>
</tbody>
</table>

¹ at 400 Amps in the coils

Except for the Q35, these magnets have been used recently and are serviceable. The Q35 represent some risk since they have been in long term storage and will need some refurbishment (some insulating parts of the water circuits and a number of temperature sensors will need to be replaced).

The optical design is described elsewhere and the corresponding layout is shown in figure 1.
Magnet Testing

It is planned, but has not been organised or resources agreed, to initiate a magnet test area to check the status of each of the conventional magnets: electrical connections, electrical insulation and water systems. This will be done in the next 6 months subject to agreements within ISIS (for mechanical support – electrical support is available).

Mechanical Design

The mechanical design and construction of the beam line is divided into three parts.
- Front end pion capture section and vacuum.
- The decay solenoid
- The matching section

These parts are actually physically separate, and the designs are being coordinated by RAL. The current status (June 2006) is that the mechanical design of the front end pion section is in progress within ISIS engineering. The commissioning of the decay solenoid and the support infrastructure is in progress within the EID design group. The design of the matching section exists in outline and will be started mid 2006.

The mechanical design of the beam line depends on the beam optical design. Sufficient stability in the optical design has been reached that the pion capture section can be designed and constructed. The mechanical tasks for the decay solenoid surround commissioning and mechanical support infrastructure are independent of the optical design.

Limitations of the beam line

For the highest momentum considered in the design (240 MeV/c), the baseline deflection angles of the two dipoles (60 and 30 degrees respectively) drives the first dipole close to saturation. This can be partly mitigated by choosing a smaller magnet gap (4") so that the field-current relationship is still nearly linear. The quadrupole magnets were originally designed for GeV proton beams and operate well within their limitations with the muon beam. The quadrupole magnets and the decay solenoid have limiting apertures. The later has a maximum field of 5T.

Pion Capture Section Engineering

An outline design has been generated which supports the three quadrupole and first dipole in the synchrotron hall. The engineering is expected to be complete by the end of June ready for manufacture well before the end of 2006. Installation is currently planned for late spring 2007.

Decay Solenoid Engineering

The decay solenoid has been inherited from the PSI laboratory in Switzerland. The planned installation of the solenoid entails modifications to the existing solenoid base.
to allow the front of the magnet to be positioned in the wall between the MICE hall and the synchrotron. A lifting frame is needed to support the solenoid during operations. The solenoid is completed by a power supply, control rack and valve panel. Initial testing of the solenoid has demonstrated continuity in the coils and insulation from ground. Vacuum integrity requires the solenoid to be moved from its current position and hence the lifting frame. The installation of the solenoid in the beam line is achieved by a rail system (the solenoid base incorporates the wheels). Jacking adjustment will be provided to align the bore of the solenoid on the beam centre line.

**Magnet Cryogenic System**

A cryogenic system has been ordered for the solenoid to supply the solenoid with helium. The specification of the system was based on operating parameters established by PSI. Final commissioning of the solenoid will take place following acceptance of the cryogenic system.

**Matching Section Engineering**

Two Q35 triplets will be mounted in the MICE hall. The positions of the triplets and the separation can be allowed to vary without disturbing the engineering work. The engineering is to be started in June 2006 with a delivery timescale of the end of 2007. Installation of this part of the beam line is planned for early summer 2007.

**Steering magnets**

The location of steering magnets in the beam line downstream of the second dipole has been considered. Steering magnets of a type used by ISIS 2nd target station have a suitable aperture. The initial locations suggest that small shelves attached to the triple frames could support these elements. Small power supplies will be required for each magnet.

**Vacuum System**

The beam line between the target and the dipole will be built as a UHV all metal sealed volume. A single ion pump (500l/s, standard ISIS equipment) will be used to maintain vacuum. An initial pump down will be required (using a portable turbo/roughing combination) during a shut down period. Vacuum gauging and pump status will be brought out to the MICE control system.

**Beam line power supplies**

Power supplies for the beam line commensurate with the highest needs of the magnetic elements will be procured by tender. The specification of the magnet supplies is given in the table. The power supply voltage takes account of the voltage drop across the supply cables and the current is specified at nominally 80% of the maximum demand expected. The power supply to D1 is an exception since the dipole would saturate and is rated at 450 A. In this case, a 500 A supply will be used. Delivery is expected by mid-2007.

The general magnet specification is a standard ISIS:

- Input power: AC 400 VRMS 3 phase 50 Hz
- efficiency: >80%
- Stability: 0.01% (1 in 10^4)
- Ripple: 0.01%
- Setting range: 1% to 100%
- Interfaces: Ethernet, RS232, EPICS controller
<table>
<thead>
<tr>
<th>Element</th>
<th>Maximum Gradient or Field</th>
<th>Current at Maximum Field</th>
<th>Recoil $\Omega$</th>
<th>Power Supply Rating, $(A,V)$</th>
<th>$kW$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1-3</td>
<td>1.6 T/m</td>
<td>160</td>
<td>0.1</td>
<td>200, 30</td>
<td>6 (x3)</td>
</tr>
<tr>
<td>D1</td>
<td>1.7 T</td>
<td>400</td>
<td>0.44</td>
<td>500, 240</td>
<td>120</td>
</tr>
<tr>
<td>D2</td>
<td>0.5 T</td>
<td>130</td>
<td>0.44</td>
<td>200, 100</td>
<td>20</td>
</tr>
<tr>
<td>Q4-9</td>
<td>2 T/m</td>
<td>320</td>
<td>0.16</td>
<td>400, 70</td>
<td>28 (x6)</td>
</tr>
</tbody>
</table>

**Beam line controls and Diagnostics**

The beam line power supplies will be self regulating to a set value. The user-control of the beam line power supplies and the monitoring of these and the status of the cryogenic system and will be via an EPICS control system yet to be implemented. The control system will provide a GUI for control of the magnets, alarms for values out of range from setting, over-temperature and other fault conditions.

Diagnostics will be provided by the instrumentation provided for MICE: a segmented scintillation detector (TOF0) will provide crude x-y information of the beam after the first triplet in the matching line. The spectrometer detector will provide detailed focusing information in real time $(x,x',x,y' \text{ etc})$ to provide visual operator feedback. In the longer term, an automated system could be employed to maximise the beam in selected tracking stations within a emittance defining ellipse.

**Beam line engineering**

The height of the ISIS beam is roughly 40cm below that of MICE. The beam line is designed without a vertical bend. Instead the beam rises from the target at ISIS beam height to that of MICE. The plane of the beam line is tilted: it is rotated about a line through the target and parallel to the solenoid. This puts a tilt on the quadrupole triplet and the dipole. The decay solenoid is horizontal.

Current beam line engineering design has concentrated on the front end part of the beam line (see figure). The vacuum tube through the quadrupoles maximises the aperture use. Slight loss of aperture is effected at the mid-point between the quads to allow bellow connections to be used. (The beam is at a maximum in the quadrupoles). Sufficient engineering has been done on the first triplet that the detailed design can be sent for manufacture.