PROGRESS OF THE NOVEL SPIRAL INJECTION TEST EXPERIMENT∗

M. A. Rehman†, SOKENDAI (The Graduate University for Advanced Studies), Kanagawa 240-0193, Japan

H. Inuma, Ibaraki University, Mito, Ibaraki, Japan

S. Ohsawa, H. Nakayama, H. Hisamatsu, K. Furukawa, T. Mibe, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

A new muon g – 2/EDM experiment at J-PARC (E34) is under preparation in order to resolve a 3 σ discrepancy of muon anomalous magnetic dipole moment between the measurement and the standard model prediction. The E34 experiment will employ a unique three-dimensional spiral injection scheme in order to store the muon beam into a small storage orbit. In order to demonstrate the feasibility of this novel injection scheme, the Spiral Injection Test Experiment (SITE) with the electron beam is under construction at KEK Tsukuba campus. The goals of the SITE are divided into two phases. In the first phase of the SITE, 80 keV DC electron beam was injected and detected as a fluorescent light due to the de-excitation of the nitrogen gas into solenoidal storage magnet. In the second phase of the SITE, the pulsed electron beam, and a pulsed magnetic kicker are developed in order to keep the pulsed beam on the very midplane of the solenoidal storage magnet. This paper describes the achievements of the first phase of the SITE and progress towards the second phase.

INTRODUCTION

The muon’s anomalous magnetic moment is one of most important measurement in elementary particle physics. The recent measurement of muon g – 2 results a 3 σ [1] discrepancy with the equally precise standard model prediction. The new J-PARC muon g – 2/EDM (E34) is under preparation to resolve current discrepancy. The E34 experiment is aiming to measure muon’s g – 2 to the precision of 0.1 ppm and EDM down to the sensitivity of 10⁻²¹ e.cm [2].

The key idea to measure muon g – 2 is to store polarized muon beam in a magnetic field and measure the evolution of spin precession vector with respect to time. In E34 a low emittance muon beam of momentum 300 MeV/c from muon accelerator will be injected into a 3-T Magnetic Resonance Imaging(MRI)-type solenoid magnet in order to store the muon beam in 0.66-m diameter orbit. In order to enhance injection efficiency and overcome technical challenges related to small storage orbit, a new three-dimensional spiral injection scheme is under development to inject the muon beam into MRI type storage magnet. Figure 1 shows the basic concept of a three-dimensional spiral injection scheme. The details and recent updates of three-dimensional spiral injection scheme can be found in [3–5].

∗ Work supported by “Grant in Aid” for Scientific Research, JSPS (KAKENHI#26287055)
† rehman@post.kek.jp

Electron Accelerators and Applications

Other electron accelerators

SPIRAL INJECTION TEST EXPERIMENT (SITE)

The SITE setup contains a 2 m long straight beamline, a solenoid storage magnet to store the electron beam and forty degrees bend section to guide the electron beam towards the storage magnet. A triode type thermionic electron gun with LaB₆ cathode is used to generate the DC electron beam of 80 keV with current in the range of few µA.

After the electron gun, a magnetic lens is placed to focus the low energy beam. A pair of steering coils also has been placed to control the transverse position of the beam. An electric chopper system has been placed after the electron gun to produce the pulsed beam. Details of the electric chopper can be found in [6]. A collimator of diameter 3 mm and depth 5 mm is placed after the electric chopper. The collimator is served as the beam dump for the chopper system and also used to create the differential vacuum system for the gas monitor in the storage magnet.

A bending magnet (BM1) is placed on the straight beamline to deflect the beam at forty degrees towards the storage magnet. A second bending magnet (BM2) is also placed near the injection point in order to control the injection angle slightly. Air core quadruple magnets have been placed on a bend section to create required beam phase space for the spiral injection. A pulsed magnetic kicker is also under development in order to keep the beam to the very center of the storage

Figure 1: Layout of three-dimensional spiral injection scheme.
The kicker system for the SITE will be discussed in the forthcoming sections. The details about each device on the straight beamline of SITE can be found in [7]. The layout of the SITE experimental setup is shown in Fig. 2 (a). The schematic of the storage magnet with a reference trajectory and monitors are shown in Fig. 2 (b). A comparison of parameters between SITE and E34 is given in Table 1.

Table 1: Comparison of Parameters between E34 and SITE

<table>
<thead>
<tr>
<th>Parameters</th>
<th>E34</th>
<th>SITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field strength</td>
<td>3 T</td>
<td>0.0082 T</td>
</tr>
<tr>
<td>Momentum</td>
<td>300 MeV/c</td>
<td>0.296 keV/c</td>
</tr>
<tr>
<td>Cyclotron Period</td>
<td>7.4 ns</td>
<td>5 ns</td>
</tr>
<tr>
<td>Storage orbit diameter</td>
<td>0.66 m</td>
<td>0.24 m</td>
</tr>
</tbody>
</table>

In the first phase of the SITE, DC electron beam was detected as fluorescent light. In the SITE nitrogen gas monitor was used to detect the DC electron beam spiral track in the storage magnet’s vacuum chamber. In the gas monitor, differential vacuum pumping has been employed to detect electron beam as a fluorescent light due to the nitrogen gas de-excitation along the beam path. The details of beam detection in the storage magnet can be found in [7].

**BEAM PHASE SPACE FOR SPIRAL INJECTION**

The radial fringe of the solenoid storage magnet requires a strongly XY-coupled beam. In Fig. 3 above four plots are showing the beam phase space at the matching point $Z = -500$ mm from the center of the storage magnet. The matching point lies outside of the storage magnet. Black points show the uncoupled beam (ideal parallel beam) and red points show the required coupled beam phase space. The bottom two plots in Fig. 3 shows the beam injection without (black) and with coupled (red) beam. In the Fig. 3 bottom left the beam start diverging vertically after $Z = -100$ mm in the case of non-coupled beam whereas in the case of appropriate coupled beam injection beam do not diverge completely at $Z = -100$ mm.

**PULSED MAGNETIC KICKER**

The pitch angle of the beam will be reduced to 0.018 rad due to the radial field of storage magnet at $Z = -100$ mm. At the $Z = -100$ mm, the vertical magnetic kicker will apply the kick to guide the beam to the very center of the storage magnet. The kicker field can be defined as follows

$$B_{kick} = B_{peak} \sin \left( \frac{2\pi}{T_{kick}} t \right)$$

where $T_{kick}$ is the duration of the kick and $B_{peak}$ represent the peak kicker field. The half sine shape has been considered for the kick, therefore, $T_{kick} = \frac{T}{2}$ and $T$ is total time period.

After the kick, the beam will be stored under the weak focusing field. In the weak focusing field the beam motion will be oscillatory in the storage volume. The weak focusing magnetic field can be defined as follows

Air core quadrupole magnets have been mounted on the bend section in order to create required beam phase space. The details calculation of TWISS and coupling parameters can be found in [3].
shows the reduction of the pitch angle due to the kicker field (c) and storage of the beam in midplane (d).

The π/6 kicker coil shape has been optimized to reduce the inductance of coils. The optimization results in the coils of height 175 mm, width 62 mm and the gap between coils was 35 mm. The total inductance of optimized coils in series has been estimated at 0.8 μH by using CST [8]. Figure 6 left shows the optimized π/6 coil shape and right shows the magnetic field map in radial and vertical directions. The kicker coil excitation current was set to 10 A for the simulation. The details of the pulsed magnetic kicker can be found in [9].

The pulsed current power supply for the magnetic kicker is also under development. The schematic of an electronic circuit for the current power supply is shown in Fig. 7.

CONCLUSION

A new three-dimensional spiral injection is under development by using the electron beam in order to realize new J-PARC’s muon g − 2/EDM experiment. An electron beamline and storage magnet has been constructed for the SITE. The electron beam in the storage magnet was confirmed as fluorescent light due to the de-excitation of nitrogen gas in the storage magnet. The required beam phase space for the spiral injection has been calculated. A pulsed magnetic
kicker and the power supply is under development to guide the pulsed beam at the midplane of the storage magnet. Particle tracking studies have been carried out with the different shapes of the kicker in the kicker and weak focusing field in order to find the appropriate magnetic field and time period for a kicker.

REFERENCES


