Status of the Superomega muon beam line at J-PARC

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Abstract

Superomega muon beamline is currently under construction at Experimental hall No. 2 of Materials and Life Science Facility at J-PARC in Tokai, Japan. The beamline has a large solid angle acceptance, and will produce the highest intensity pulsed muon beam in the world. The beamline is designed to capture both surface positive and cloud negative muons for simultaneous use in a variety of experiments. The expected rate of surface muons for this beamline is \(4 \times 10^8\) \(\mu^+\)/s, and that for cloud muons is \(10^7\) \(\mu^-\)/s. The beamline consists of the normal-conducting capture solenoid, the superconducting curved transport solenoid and axial focusing solenoid. The construction of the capture solenoid has been completed and installed in March 2009, and the transport solenoid is now fabricated, and will be installed by the end of 2011. The conceptual design of the axial focusing solenoid is completed, and the mechanical design is underway.

1. Introduction

Superomega is the second muon beamline among four planning muon beamlines at the Materials and Life Science Facility (MLF) at J-PARC[1], and is currently under construction for aiming the extraction of the first muon beam in the autumn of 2011. The 3 GeV proton beam injected into the MLF is incident on a graphite muon production target in order to produce muons for use in various experiments. The Superomega extends at 45 degrees into the backward angle from the primary proton beam. The Superomega is a new type of beamline for a muon source, since all beamline magnets consist of solenoidal coils, whereas the magnets

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of the conventional muon beamlines consist of quadropole and bending magnets [2]. It is capable of not only capturing and transporting the both positive surface muons and negative cloud muons for simultaneously use of the various experiments, but also extracting a high intensity muon beam into the experimental hall No. 2 of MLF. While the beam intensities of conventional beamlines are limited, in large part, by their relatively small solid angle acceptance to capture muons, the Superomega will have a large solid angle acceptance of 400 msr, because of solenoidal capture coils. The expected intensity of the positive surface muons for this beamline is $4 \times 10^8 \mu^+/s$, and that of the negative cloud muons with the momentum up to 45 MeV/c is $10^7 \mu^-/s$. This means that the Superomega will be the highest pulsed muon source in the world.

2. Design of Superomega Beamline

The Superomega muon beamline consists of three parts, a normal-conducting capture solenoid, a superconducting curved transport solenoid and an axial focusing solenoid. The capture solenoid captures up to $5 \times 10^8$ positive surface muons/s and in excess of $10^7$ negative cloud muons at 30 MeV/c. The curved solenoid efficiently transports captured muons through the beamline tunnel, which shields radiation from the primary proton beamline and muon production target, into the experimental hall No. 2 of MLF. The axial focusing solenoid further transports the muons about 6-m long inserting apparatuses, such as muon beam blocker for safety operation in the experimental area and positron separator for eliminating involved positrons as impurities for muon beam, and focuses onto experimental target for individual use of the several experiments, such as ultra slow muon production and muon transfer experiment. The muon transport rate and beam trajectory are simulated using a GEANT4 based Monte Carlo simulation program, called G4Beamline[3], and the magnetic field distribution and the magnetic forces onto the individual solenoids are calculated using TOSCA.

2.1. Normal-conducting Capture Solenoid

The front face of the capture solenoid is placed at 0.6 m from the muon production target into backward angle of 45 degrees from the primary proton beam. The capture solenoid can captures muons produced at the
muon production target with a large solid angle acceptance of 400 msr. For avoiding radiation damage from
the muon production target and the primary proton beam, the solenoid is wound using radiation-resistant
mineral insulation cables (MIC), with a maximum allowable current of 2000 A. The capture solenoid consist
of six coils. Four coils located upstream and two downstream coils are connected in series individually.
The operating current for capturing muons with momentum of 30 MeV/c is approximately 1000 A for the
upstream coils and 200 A for the downstream coils. The peak central field of the capture solenoid is about
0.3 T for capturing muons with momentum of 30 MeV/c. The field measurements for capture solenoid
have been performed and seen to agree with TOSCA calculations up to 1500 A for the upstream coils[4].
Fabrication of the capture solenoids was completed in March 2008, and they were installed on the beamline
in March 2009.

2.2. Superconducting Curved Transport Solenoid

The curved solenoid transports the captured muons through the secondary beamline tunnel into the
experimental hall No. 2. The solenoid consists of a 6 m long straight section placed between two 45 degrees
curved sections. The curved section is divided into seven segmented thin solenoids with angle between
each solenoids of 5.625 degrees. In order to compensate a stray field from the straight section, matching
solenoids place at the entrance and the exit of curved solenoid. To satisfy the feasibility of fabrication of
the solenoid, the straight section divides into five 1.2-m long solenoids. These sixteen solenoids, except for
exit solenoid, are connected in series, while exit solenoid can be adjusted separately with the axial focusing
solenoid. On the straight section, two dipole coils, which produce vertical opposite fields with a integrated
field of 0.2 Tm, are located near the center of the straight section. They provide charge selection required
by use of only positive muons or negative muons. For steering the beam direction and position of the beam
center at the exit of curved solenoid, two dipole correction coils with the vertical and horizontal fields are
located at center of the exit solenoid.

A superconductor is commonly used for the solenoids and the dipoles. The solenoid coils use 85 A in
series and the dipoles uses 77 A individually. All of the cold masses, superconducting solenoids and dipoles,
are designed to be conductively cooled by five Gifford-McMahon (GM) refrigerators with capacity of 1.5 W
at 4.2 K (2nd stage) and 35 W at 50 K (1st stage).

The muon transport rate of capture and transport solenoids was simulated using G4Beamline. Captured
muons by the capture solenoid are estimated to be $5 \times 10^8$ muons/s, when 3 GeV primary proton beam is
incident on the muon production target. The simulation results show that the total transport rate of captured
muons with momentum of 30 MeV/c is 82% at the exit of the curved solenoid. This corresponds to $4 \times 10^8$
muons/s that are extracted into the experimental area[5]. A majority of the beam loss occurs at a gate
valve located between capture and curved solenoids. This means that almost all muons incident on curved
solenoid are transported to experimental hall No. 2.

The curved transport solenoid is currently under fabrication by Toshiba Co., and will be installed by the
end of 2011.

2.3. Superconducting Axial Focusing Solenoid

The axial focusing solenoid consists of twelve thin superconducting solenoids. Two solenoids are placed
into a cryostat with a gap of 200 mm, are conductively cooled down by one GM refrigerator. Since the
cryostat has a warm bore, the vacuum ducts of the muon beamline are located at the center of bore. Four
pairs of upstream solenoids are designed to further transport the muon beam and to make beam nodes in
spaces of the beam blocker and positron separators. Two pairs of residual solenoids are used for focusing
the muon beam onto the experimental target.

A muon beam blocker and positron separator must be placed in the axial focusing solenoid system.
When users work in the experimental area, the beam blocker must be inserted to the beamline in order to
reduce radiation exposure through the beamline duct to the experimental area.

The positron background should be eliminated for improving the muon beam quality. Three-stage sep-
arators of Wien filter type are placed in the space between cryostats in order to eliminate the positron
background efficiently. The demension of electrodes of the separators are 750 mm in length and 500 mm in
Fig. 2. The vertical envelopes (3 $\sigma$) of the muon (solid line) and the positron (dashed line) beams in the axial focusing solenoid with applying voltage of $\pm 300$ kV to the separators. The c-shape lines represent the positions of the thin solenoids and the separator electrodes.

width, and the gap between the electrode is 300 mm. The electrodes can be applied with voltages of up to $\pm 400$ kV (upper electrode is negative), and integral magnetic field of the correction coil is 0.375 Tm. Figure 2 shows the vertical envelopes (3 $\sigma$) of the muon and the positron beams in the axial focusing solenoid with applying the voltage of $\pm 300$ kV and the field of 0.28 Tm to the separators. The trajectory of the muon beam is not affected through the three separators, while the positron beam is gradually deviated downwards. Almost all positrons can be eliminated by hitting the beamline ducts and the third lower positive electrode.

The beam transport simulation of the axial focusing solenoid has been complete. The mechanical designs of the cryostat, the separator, beam blocker and the beamline ducts are currently underway. The fabrication of the axial focusing solenoid will be completed by the end of fiscal year of 2011.

3. Summary

The Superomega beamline, the second muon beamline of MLF/J-PARC, is under construction. Although the construction schedule of the Superomega beamline is currently slight delay by the strong earthquake in Japan, we shall advance the Superomega project as scheduled. The normal conducting capture solenoid has been installed in March 2009. The superconducting curved transport solenoid is currently fabricated by Toshiba Co., and will be installed by the end of 2011. The first beam extraction experiment of the Superomega beamline (without the axial focusing solenoids) will be conducted in March 2011. The conceptual design of the axial focusing solenoid is completed, and it is expected to be fabricated by the end of March 2012.

References

[3] Muons, Inc. 552 Nm Batavia Avenue, Batavia, IL.