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CONCEPTUAL DESIGN OF NEGATIVE-MUON DECELERATOR FOR MATERIAL SCIENCE

C. Ohmori*, M. Otani, K. Shimomura, KEK/J-PARC, Tokai, Ibaraki, Japan
T. Takayanagi , JAEA/J-PARC, Tokai, Ibaraki, Japan

Abstract

In 2018, a Negative-Muon Spin Rotation and Relaxation technique was developed in J-PARC Material and Life Science Facility. It is a novel scheme to investigate the motion of hydrogens in chemicals and materials. In the experiment, 50 MeV/c μ^- beam and thick sample were used to maximize the number of stopped muon in it. To study small samples, the surface of materials and thin foils, a low energy negative muon beam is required. In the present muon beam line, however, the intensity of low energy negative muon is almost zero. To decelerate intense 300-keV muons to 15-keV, we propose a system which consists of pulse generators and multi-gap induction decelerators. In this design, Linear Transformer Driver scheme is considered to use for the high voltage pulse source. High impedance magnetic alloy ring cores will be loaded in the decelerator cells. The high impedance cores which have much larger size than those for public use were developed for J-PARC RF systems and used for many applications including CERN booster RF, anti-proton deceleration and medical accelerator. In this paper, we present a conceptual design of muon deceleration system.

INTRODUCTION

J-PARC Material and Life Science Facility, MLF, uses very high intensity 3 GeV proton beam to produce neutrons and muons. A unique feature of the MLF is negative muon beam which is more intense than other facilities. Recently, the world-first μ^-SR signal was observed at the MLF [1]. In case of standard μ^+SR, the positive muon can move around because it has positive charge. However, the negative muon is trapped in heavy nuclei. During trapping, the negative muon is affected the other field, for example, hydrogen around the nuclei. Such field is sensitive for the motion of hydrogen and μ^-SR will be a good tool to see it. However, the energy of negative muon is high to investigate small and thin samples. Although the low energy negative muon of few ten keV is required, the intensity of low energy muon is very very low. Therefore, the deceleration of few hundred keV muon is proposed.

CONCEPTUAL DESIGN OF MUON DECELERATION

In the MLF, the negative muon is available at D2 beam line which has a flexibility to use positive and negative muon beams. The D2 experimental area is 5 m×5 m wide (see Fig. 1). The deceleration system should be shorter than 3 m because it will be located in front of the μ^-SR spectrometer. And, it is also required that the deceleration energy can be changed to use the μ^- beam for samples with different thickness. The muon deceleration system should be easily moved from the experimental area because the area will be shared with the other experiments. The normalized emittance of μ^- is estimated to be 1000πmm.mrad before deceleration at 300 keV. Because of these requirements, the induction-cavity base decelerator is considered. Figure 2 shows the induction decelerator system. It consists of following components:

- 6 induction decelerator units
- 2 sets of 25 Ω dummy load
- 2 sets of 50 kV inductive adder [2] or Linear Transformer Drivers, LTD [3]
- quadrupole magnets between induction decelerator units.

Through the 4-cell and 2-cell cavities, the muon beam will be decelerate to below 30 keV as shown in Fig. 3.

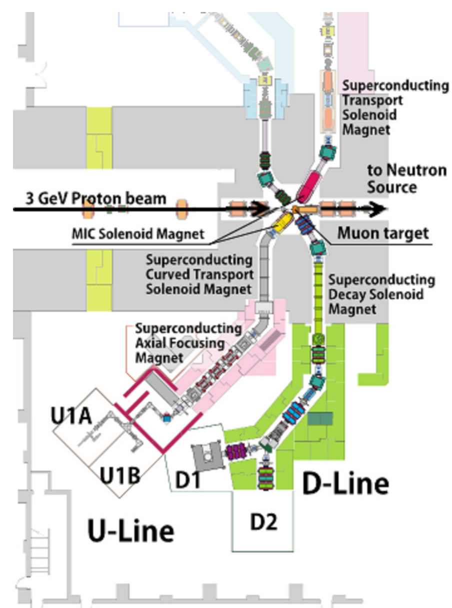

Figure 1: D2 experimental area and beam line.

Cavity Cell

The deceleration cavity consists of 4-cell and 2-cell cavities. Between two cavities, a triplet of quadrupole magnets is inserted. In each cell, 5 magnetic alloy, Finemet FT3L, cores are installed [4]. The size of core is 500 mm outer diameter, 192 mm innder diameter and 25.2 mm thickness. The core impedance is 122 Ω and 16 μH at 1 MHz. Circuit simulations using LTSpice were performed to investigate the gap voltage for μ^- deceleration. The circuit model for

* chihiro.ohmori@kek.jp

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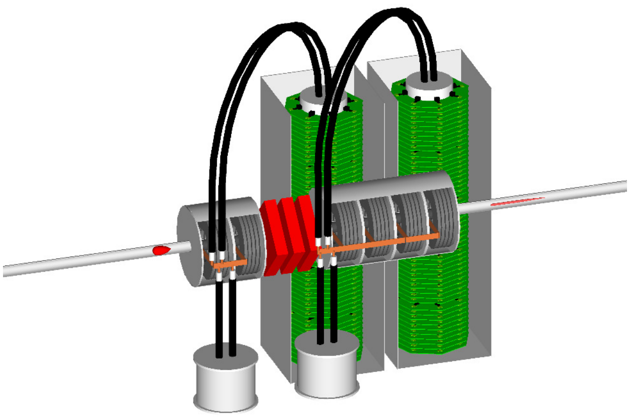

Figure 2: Induction decelerator system.

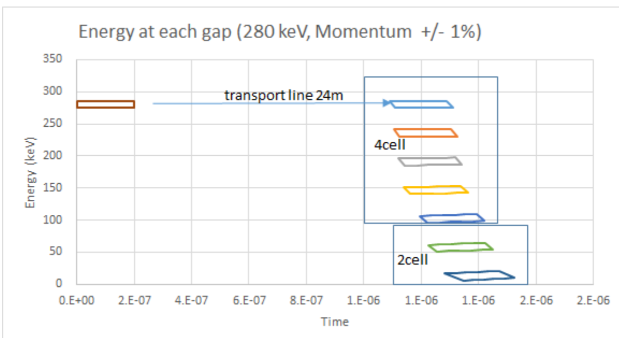

Figure 3: Deceleration through 4-cell and 2-cell cavities.

4-cell cavity is shown in Fig. 4. The cavity impedance is estimated by the size of FT3L core. Figures 5 and 6 show the gap voltage and drive current of 4-cell and 2-cell cavities. Because of limited cavity impedance, the gap voltage show the sug of 3 kV at the top in case of 4-cell cavity. The width of the flat top is 400 ns and it is wider than the muon bunch. The effect by the sug will be limited because the width of μ^- beam buch is 200 ns. Thefore the sug will not be a problem in case of single bunch deceleration. The muon beam will be decelerate 185 kV in the 4-cell cavity and 105 kV in the 2-cell one. In case of two bunch operation, the saturation of induction cores will be an issue as the magnetic field will be higher than the saturation, B_s, of the material. To avoid the saturation by a long pulse, the outer diameter of the core will be 800 mm. The 800 mm cores are available and used in the J-PARC MR.

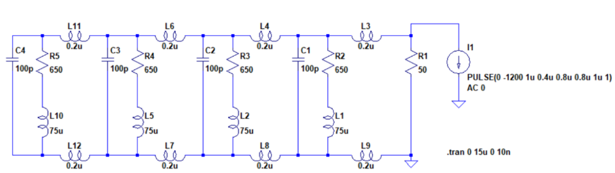

Figure 4: Circuit model of 4-cell type Induction decelerator system.

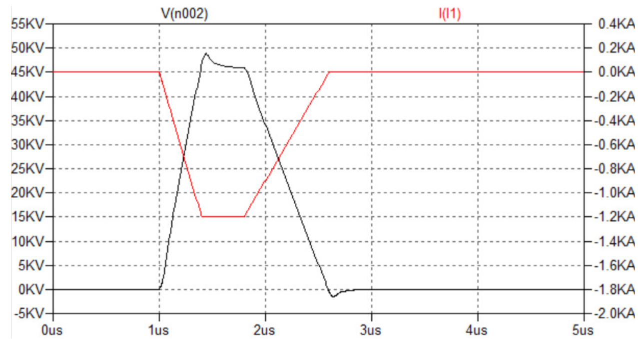

Figure 5: Deceleration voltage of 4-cell type Induction decelerator system.

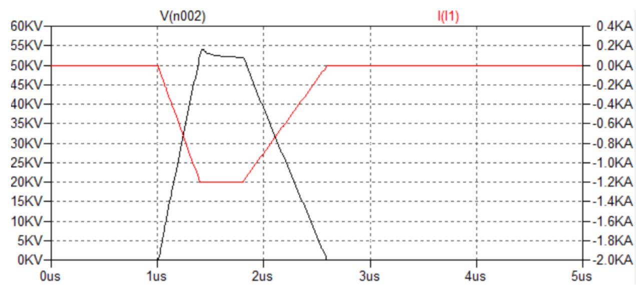

Figure 6: Deceleration voltage of 2-cell type Induction decelerator system.

Optics

The beam simulation was performed based on the transfer matrix calculation code, TRACE3D [5]. The beam emittance of μ^- was estimated from the present decay μ^+ beam. For the 300 keV decay muon, the normalized beam emittance is 1000 πmm mrad. And, we assumed that horizontal beam emittance is 20 % larger than the vertical one. The location of quadrupole magnets were searched. The result is shown in Fig. 7. Although the beam size at the target point is about 100 mm, the muon intensity will be several hundred Hz at 30 mm target because the intensity of 300 keV muon is about 8 kHz. The rate of several hundred Hz almost satisfies the minimum requirements for μ^-SR measurement.

Further optimization will be performed on beam optics. There is another option to improve as shown in Fig. 8. In this case, decelerating units were devided in 3. And, doublet and triplet quadrupole magnets will be used.

Pulse Power Supply

The pulse power supply is another key instrument. We are considering two options: Inductive Adder and Linear Transformer Driver, LTD [3]. Both scheme use the transformer cores and solid state devices for swithching. In the J-PARC RCS, the LTD-type pulse power supply is under developing for the extraction kicker system to replace the present one using Thyratrons [6–8]. Figures 9 and 10 show a LTD module and schematics of the RCS kecker system. Parameters of the LTD system for muon deceleration are listed in Table 1.

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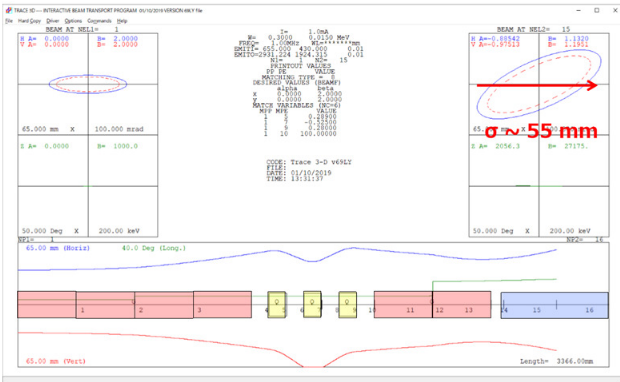

Figure 7: The beam emittance before and after deceleration.

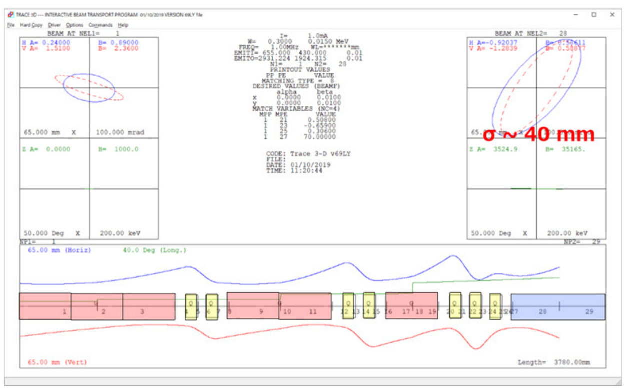

Figure 8: The beam emittance before and after deceleration in case of another option.

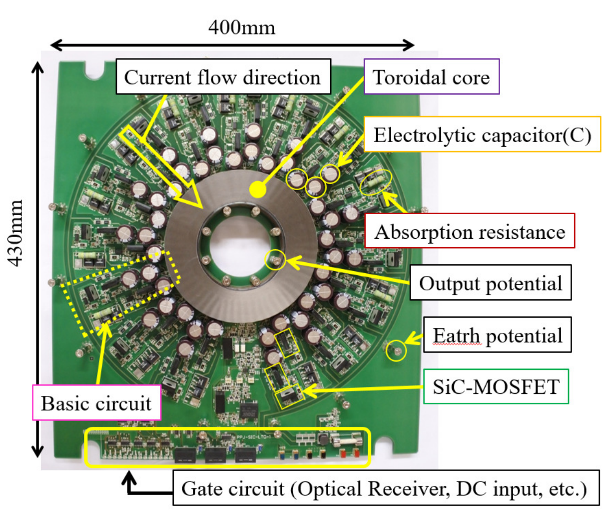

Figure 9: A main LTD module.

SUMMARY AND OUTLOOK

A conceptual design of negative muon deceleration system was described. A 300 keV muon beam will be decelerated to below 30 keV by induction-decelerating cavities. Beam optics calculation shows that several hundred Hz muons will be supplied on a large sample for μ^-SR experiment. Further works will be necessary to improve the muon beam intensity.

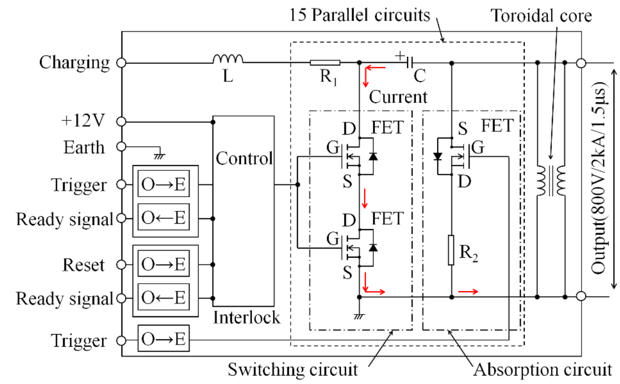

Figure 10: The schematics of LTD module.

Table 1: Pulse Power Supply

Parameters	Value	unit
Output current	1.2	kA
Rise/Fall times	200-500	ns
Flat Top	>300	ns
Repetition	25	Hz

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