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LOW POWER MEASUREMENT OF A 1300-MHz RFQ COLD MODEL

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Abstract

A muon linac development for a new muon g-2 experiment is now going on at J-PARC. Muons from the muon beam line (H line) at the J-PARC muon science facility are once stopped in a silica-aerogel target, and room temperature muoniums are evaporated from the aerogel. They are dissociated with lasers, then accelerated up to 212 MeV using a linear accelerator. In the current reference design, a 324-MHz radio frequency quadrupole (RFQ) and an interdigital H-mode drift tube linac (IH-DTL) are used for the low beta acceleration. We propose a 1300 MHz (L band) RFQ instead of the 324 MHz RFQ and IH-DTL as an alternative to simplify the configuration of the muon linac. In this paper, the present status of the design and the measurement of a cold model of this world first 1300-MHz RFQ is described.

INTRODUCTION

The muon anomalous magnetic moment $(g-2)_\mu$ is one of the most promising probe to explore the elementary particle physics beyond the standard model (SM). Currently, the most precise $(g-2)_\mu$ experiment is E821 of Brookhaven national laboratory [1]. The precision is 0.54 ppm and the measured value indicates approximately three standard deviations from the SM prediction. The J-PARC E34 experiment aims to measure the $(g-2)_\mu$ with a precision of 0.1 ppm. In addition, the electric dipole moment (EDM) also can be measured with a precision of $1 \times 10^{-21} e\cdot$cm [2]. The experimental method of E34 is completely different from that of the previous experiments. The previous experiments directory used decay muons from the secondary pions generated on the production target. The emittance of such muon beam is very large (typically, 1000π mm mrad); this is a major source of uncertainty of the measurement. On the other hand, E34 will use a low emittance muon beam to improve the precision. The required beam divergence $\Delta p_t/p$ is less than 10^{-5}, and assumed transverse emittance is 1.5π mm mrad. To satisfy this requirement, we are planning to use ultra-slow muons (USMs) generated by laser-dissociation of thermal muoniums (Mu: μ^+e^-) form a silica-aerogel target [3]. The room temperature USMs (25 meV) should be accelerated to 212 MeV to obtain the required $\Delta p_t/p$. A linac realizes rapid acceleration required to accelerate muons, whose lifetime is very short (2.2 µs). Figure 1 shows the configuration of the muon linac [4].

The muon linac will be constructed at the H line [5] of the J-PARC muon science facility. The USMs are bunched and accelerated to 340 MeV by a radio frequency quadrupole linac (RFQ). Following the RFQ, an interdigital H-mode drift tube linac (IH-DTL) [6] is used to accelerate to 4.5 MeV.

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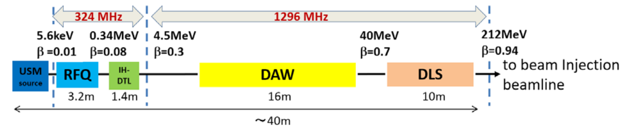

Figure 1: Configuration of the muon linac.

Then, muons are accelerated to 40 MeV through a disk and washer (DAW) coupled cavity linac section, and finally, accelerated to 212 MeV using disk loaded traveling wave structures (DLS) [7].

To reduce the development costs, a spare RFQ for the J-PARC linac will be used, therefore, the resonant frequency is 324 MHz. Removing the restriction to use the J-PARC RFQ, if the same frequency of the following linac, which is 1.3 GHz (L-band), can be used, is becomes reasonable because only one type of the RF source should be prepared. In case of the proton acceleration, the cell length for 50 keV, which is typical injection energy to the RFQ, is $\beta\lambda/2 = 1.2$ mm: this is too short to fabricate. On the other hand, for muon acceleration it becomes a feasible length of 3.5 mm. Therefore, we propose to replace the 324-MHz RFQ and IH-DTL by an 1300-MHz RFQ shown in Table t̊bl:requirement as an alternative of the muon linac baseline design. In this paper, the present status of the design of the 1300-MHz RFQ and low-power measurement of a cold model.

Table 1: Requirements for the 1300-MHz RFQ

Parameter	Value
Beam species	μ^+
Resonant frequency	1296 MHz
Injection energy	30 keV
Extraction energy	5.2 MeV
Peak beam intensity	1×10^6
Transverse emittance (normalized rms)	$< 0.25\pi$ mm mrad
Repetition rate	25 Hz
RF pulse length	20 µs
RF duty factor	0.05%

DESIGN OF THE 1300-MHz RFQ

The beamdynamics design of the 1300-MHz RFQ has been done using RFQGEN [8]. Figure 2 shows the cell parameters, and the obtained design parameters are listed in Table 2. In this design, the average bore radius r_0 is kept same as that of the 324 MHz RFQ to be acceptable the present injection muon beam. Due to this design concept, the power dissipation is rather high. The matching between the RFQ and injection design is an issue from now on.

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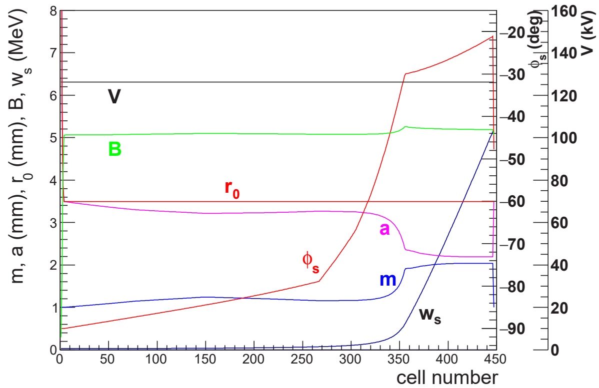

Figure 2: Cell parameters of the 1300-MHz RFQ.

Table 2: Design Parameters of the 1300-MHz RFQ Obtained with RFQGEN

Parameter	Value
Vane length	3.7 m
Number of cells	448
Inter-vane voltage	126 kV
Maximum surface field	53.0 MV/m (1.65 Kilpatrick)
Average bore radius (r_0)	3.50 mm
ρ_t/r_0 ratio	0.75 (ρ_t = 2.62 mm)
a_{min}	2.23 mm
m_{max}	2.19
$\phi_{s,max}$	-21.1 deg

Figure 3 shows the result of the particle simulation. The transmission is 100% for the injection beam with a normalized rms emittance of 0.2π mm mrad, and the normalized rms transverse and longitudinal emittances at the RFQ exit are 0.26π mm mrad and 0.095π MeV deg, respectively. The decay loss of the muon for this RFQ length is 8%.

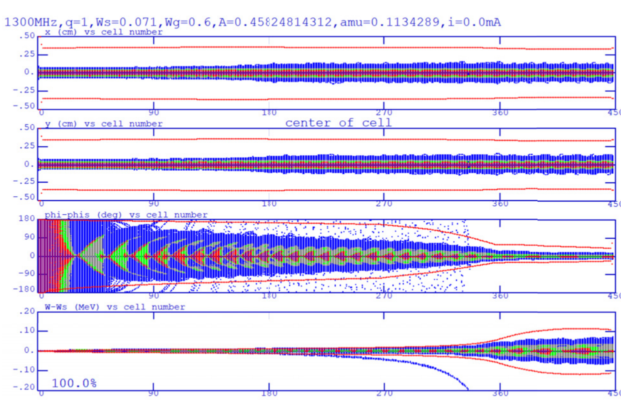

Figure 3: Phase-space evolution of the 1300-MHz RFQ.

Based on this beamdynamics design, the cross-sectional shape of the cavity was designed using RFQFISH [9], as shown in Fig. 4. Calculated Q value is 6554 and power dissipation is 3 MW. The dimensions of the vane endcuts

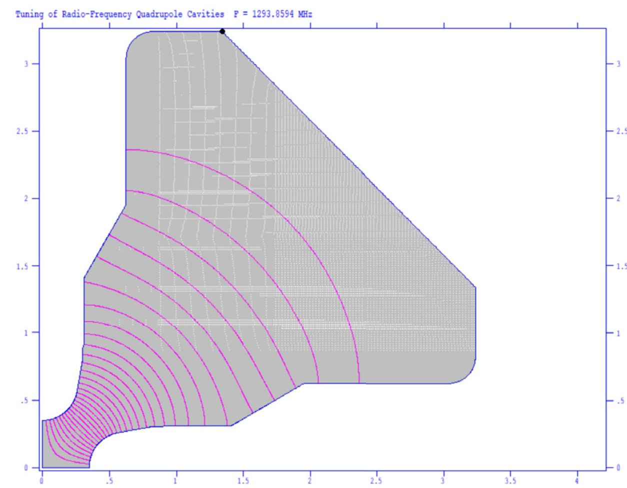

Figure 4: Cross-sectional view of the 1300-MHz RFQ.

were determined by tree-dimensional calculation using CST Micro Wave Studio (MWS) [10]. The resonant frequency of the half-length model with the endcuts was tuned to be same as the infinite-length model without endcuts.

COLD MODEL OF THE 1300-MHz RFQ

Based on the obtained design in the previous section, a cold model with a length of 450 mm was fabricated. Figure 5 show this cold model together with a 324-MHz RFQ as a reference.

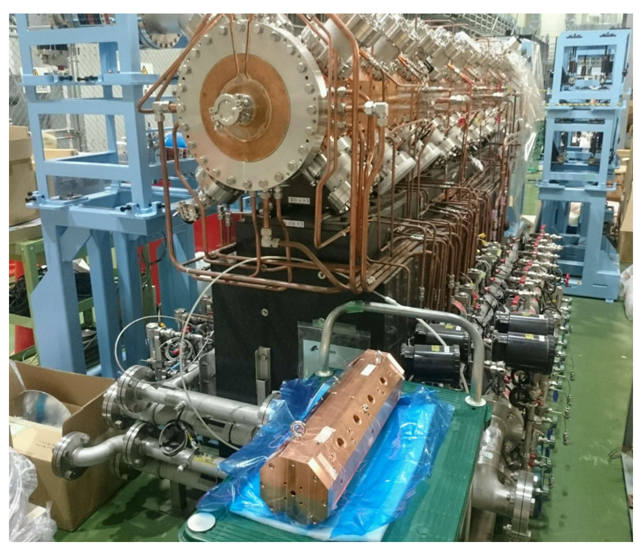

Figure 5: The 1300-MHz RFQ cold model together with a 324-MHz RFQ.

To confirm the RF property, an aluminum model is enough, however, this cold model is made of oxygen free copper (OFC) to confirm also the machining accuracy. Figure 6 shows the result of the coordinate measurement of the vane tips. Except for the downstream side of the major vane 1, the discrepancy from the design value is within ±15 µm. Although the machining accuracy of major vane 1 itself is also within ±15 µm, the overall accuracy is worsen due to a warp of the vane; it is an issue from now on.

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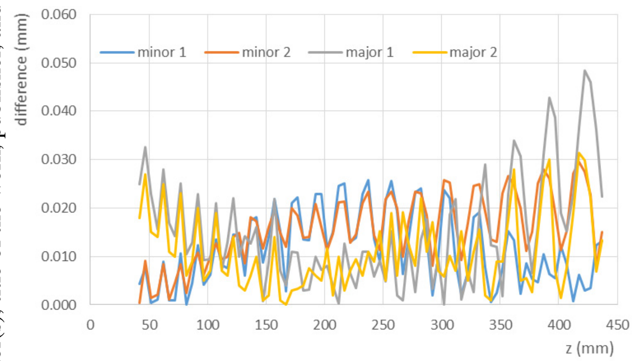

Figure 6: Coordinate measurement of the vane tips.

Figure 7 shows the interior view of the cold model. The outer diameter of the cavity is 135 mm. It is equipped with four tuners and five pickup ports per one quadrant. The tuners are threaded plugs made of OFC.

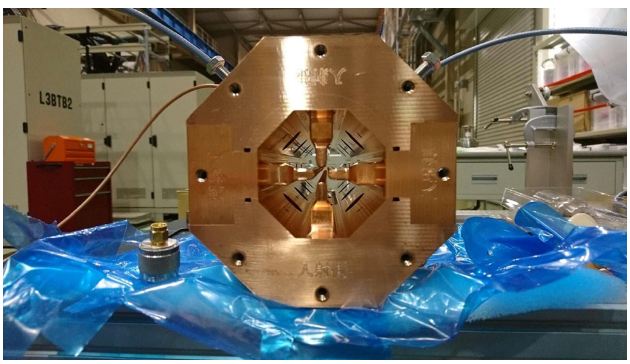

Figure 7: Interior view of the 1300-MHz RFQ cold model.

Figure 8 shows the eigenmode frequencies of the cold model. This measurement was done without tuners. The 1284 MHz peak is consistent with the calculated TE210-mode frequency of the MWS model without tuners.

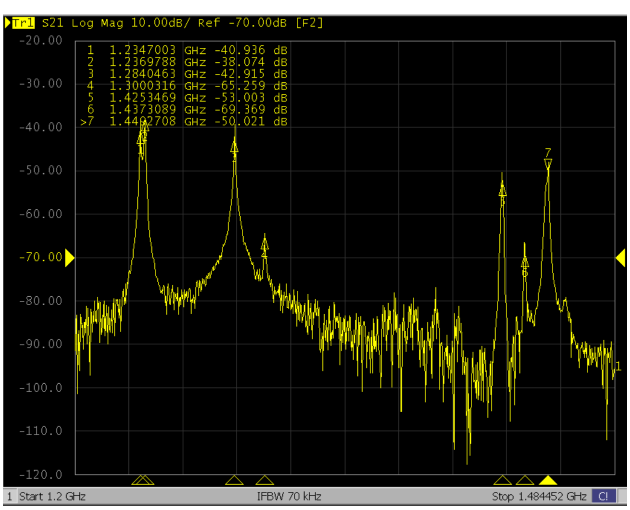

Figure 8: Eigenmode frequencies of the 1300-MHz RFQ cold model.

A bead drive system for this cold model is now under preparation, but preliminary measurement was conducted to confirm this mode to be a fundamental quadrupole mode. Figure 9 represents the result. The S_{21} parameter was measured by connecting the port 1 of the network analyzer to a pickup of the quadrant 1 and the port 2 to quadrant 4. A bead is inserted in the quadrants 2 and 3, and the phase difference at 1284 MHz was plotted in Fig. 9. Four dents correspond to sinks of the field due to the tuner ports. The measured field strength of the quadrants 2 and 3 are almost same and the distribution is flat. Therefore this eigenmode frequency is identified as TE210 mode.

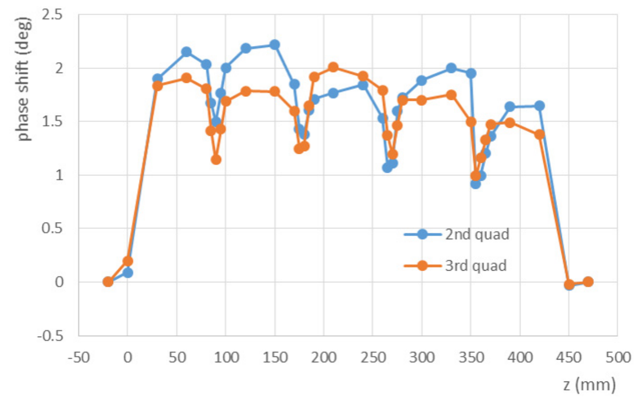

Figure 9: Preliminary bead-pull measurement.

SUMMARY

We proposed a 1300-MHz RFQ as an alternative of the low energy section of the muon linac. RFQs with this frequency have not been realistic due to the very short cell length even for proton acceleration. However, for muon acceleration, the cell length becomes fabricable length. For feasibility studies, a cold model of the 1300-MHz RFQ was fabricated and frequency and preliminary bead-pull measurement have been conducted. The bead-pull system for this RFQ is now under preparation, and after the system is ready, we will tune the frequency and fields.

ACKNOWLEDGEMENTS

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