Beam test using new central region for energy upgrade at RIKEN AVF cyclotron†

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The structure of the central region of the AVF cyclotron was renovated in 2009 (S1), and the available energy for M/Q = 2 ions was increased from 9 MeV/u to 12 MeV/u.[1)] After this modification, in order to further increase the beam energy of protons to 30 MeV, another structure (S2) which enables an acceleration with a harmonic number (h) of 1 instead of 2 was designed.[2)] Figure 1 shows the superimposed plan views of the structures S1 and S2. In structure S2, the RF shield is smaller than that of S1, the second acceleration gap was moved downstream and the outside wall at the exit of the second gap was removed. Figure 2 shows the acceleration performance of the AVF cyclotron for the three structures of the central region. The acceleration of the 20–30 MeV proton uses the harmonic number h = 1.

We replaced the central region S1 with S2 and performed beam acceleration tests in August 2016. In addition to the acceleration test with h = 1, we investigated the influence on the transmission efficiencies through the cyclotron in the h = 2 operation. Table 1 presents a summary of the acceleration tests. A total of seven beams were accelerated. As the scheduled time for study was limited, the mean beam tuning time for the acceleration of one beam was approximately 4 h. In Table 1, I36 and C01 indicate the beam currents at Faraday cups FC-I36 and FC-C01 located at the injection and extraction beam lines of the AVF cyclotron. In the h = 1 operation, while 20-MeV protons were successfully accelerated with a beam current of 10 μA, the beam current for 30-MeV protons was as small as 1.1 μA because the dee voltage was insufficient owing to the deterioration of the RF cavities. In the h = 2 operation, the extracted beam currents at the FC-C01 for 14-MeV protons, 12-MeV/u deuterons and $^{22}Ne^{7+}$ were almost the same as those in the S1 configuration. However, the transmission efficiency for $^{22}Ne^{5+}$, which simulates $^{84}Kr^{20+}$, was approximately 60% of the peak performance to date. The transmission efficiency for $^{56}Fe^{15+}$ beams was only 10%, while its efficiency has so far greater than 20% or occasionally 30%. It can be concluded that the transmission efficiencies in the h = 2 operations with S2 were rather poor compared to those with S1, although the time for machine study was not sufficient. Therefore, we decided to revert the tested structure, S2, to the existing one, S1. At present, we are attempting to clarify the reason why the transmission efficiency was low and search for a new geometry that realizes higher transmission efficiencies for both h = 1 and h = 2 operations through a beam simulation study.

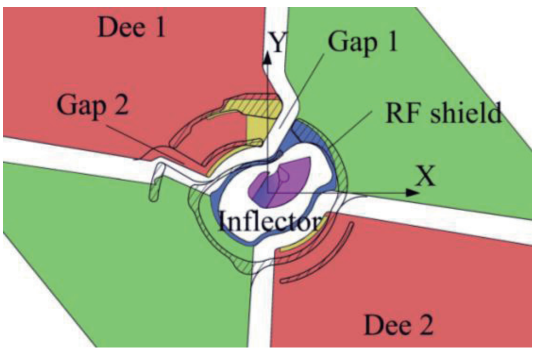

Fig. 1. Existing and tested geometries of the central region. The shaded area indicates the existing geometry.

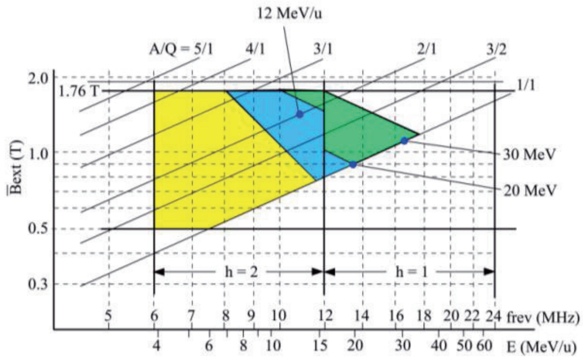

Fig. 2. Acceleration performance of the AVF cyclotron. The yellow, blue, and green areas correspond to the original (before 2009), existing (S1), and currently tested (S2) geometries, respectively.

Table 1. Summary of acceleration test.

Ion	Energy	RF frequency (MHz)	Harmonics	I36 (μA)	C01 (μA)
p	14 MeV	23	2	90	14.3
H_2^+	12 MeV/u	21.25	2	57	9.6
$^{22}Ne^{7+}$	6.0 MeV/u	15.05	2	42	7.5
$^{22}Ne^{5+}$	4.0 MeV/u	12.3	2	12	2
p	20 MeV	13.6	1	76	10
p	30 MeV	16.5	1	116	1.1
$^{56}Fe^{15+}$	5 MeV/u	13.8	2	1.2	0.12

References
1) A. Goto et al., RIKEN Accel. Prog. Rep. **43**, 127 (2010).
2) S. B. Vorozhtsov et al., RIKEN Accel. Prog. Rep. **44**, 105 (2011).

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