Operation report on the RIKEN AVF cyclotron for 2021

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The annual report on the operation of the RIKEN AVF cyclotron (hereafter denoted as AVF) for the period January–December 2021 is presented. The beams accelerated using AVF in the period are listed in Table 1, where beam currents are the maximum values measured by the Faraday cup FC-C01 at the exit of AVF. The operation statistics are summarized in Table 2. The operation time for stand-alone operation was increased to 2100 h from 1520 h, which was reduced because of the COVID-19 outbreak in 2020. Moreover, the operation time for injection to RRC was also increased to 1816 h from 1182 h because the acceleration in the AVF-RRC-SRC mode was performed for the first time in three years from May to June, and ^{2}H, ^{4}He, and ^{12}C beams were supplied to experiments for 28 days.

To supply high-quality beams required for the experiments and to reduce beam losses in two cyclotrons (RRC and SRC) downstream of AVF, AVF was tuned to extract single turn beams so that components of different turns were minimized in the extracted beams. The minimum mixing rate for ^{2}H beam was 2.3% ± 1.3%.

In the stand-alone operation which supplied $^{7}Li^{3+}$ at 8.3 MeV/nucleon, the highest beam current of 5670 particle nA was achieved at FC-C01, which was increased by 2.4 times compared with that recorded at a slightly different energy of 8.6 MeV/nucleon in an acceleration test performed in 2011. The increase was because of a high beam current of 70000 particle nA extracted from the Hyper ECR ion source owing to a modification of an extraction electrode, as well as a research for supporting gases.

A main trouble occurred at each compensator for two Dees, which was used to tune a resonant frequency by changing the capacitance. When compensator #2 was rotated, a vacuum was leaked through a driving shaft, so that a vacuum degree of the main chamber deteriorated from 10^{-5} Pa to 10^{-3} Pa. In the repair process, the other leakage was found from compensator #1. The vacuum was recovered by replacing the X-rings.

As a recent improvement, we started monitoring temperatures at the tips of septum electrodes for the electrostatic deflector using a pair of thermocouples. The monitor signals are fed into the beam interlock system (AVF-BIS), so that beams are stopped automatically by a chopper and a Faraday cup, which are located before injection to AVF, if an increase of the temperature caused by beam loss exceeds a certain value. Currently, the preset value is 45°C.

Table 1. AVF beam list in 2021.

Particle	Energy [MeV/nucleon]	Acceleration Mode	Experimental Course	Beam Current at C01 [particle nA]
$^{1}H^{+}$	19	AVF	E7V/RI production	10000
	30		C03/RI production	10000
$^{2}H^{+}$	4.93	→RRC→SRC	BigRIPS	7000
	12	AVF	C03/RI production	19800
	15		C03/RI production	13000
$^{4}He^{2+}$	4.17	→RRC→SRC	BigRIPS	1670
	6.5	AVF	E7B/Student	6000
	7.25		C03/RI production	25000
			E7B/RI Production	
	12.5		C03/RI production	3850
$^{7}Li^{2+}$	6		C03/RI production	8000
$^{7}Li^{3+}$	8.3		E7A/CRIB	5670
$^{12}C^{4+}$	4.93	→RRC→SRC	BigRIPS	1130
	7	→RRC	E5B/Biology	880
			E5A/Industry	
$^{14}N^{5+}$	5.54		E3B/Industry	450
$^{16}O^{6+}$	6.8	AVF	E7A/CNS	4080
$^{18}O^{6+}$	7		E7V/CNS	4580
$^{20}Ne^{7+}$	7	→RRC	E5B/Biology	540
$^{40}Ar^{11+}$	3.8	→RRC→IRC	E5B/Biology	390
	5.2	→RRC	E5A/Industry	520
$^{56}Fe^{15+}$	5.01		E5B/Biology	110
$^{84}Kr^{20+}$	3.97		E5A/Industry	230

Table 2. Comparison of AVF operation statistics with that in the previous years.

AVF stand-alone operation	Year 2019	2020	2021
Tuning of AVF [h]	1314	744	1149
Trouble of AVF [h]	0	1	5
C01 MS [h]	0	12	35
C03 Exp [h]	873	631	672
E7V Exp [h]	36	18	95
E7A Exp [h]	790	12	48
E7B Exp [h]	153	101	96
Sub total [h]	3166	1519	2100
AVF operation as injector of RRC	Year 2019	2020	2021
Tuning of AVF [h]	118	178	214
Trouble of AVF [h]	0	5	1
RRC-Exp (-IRC-Exp) [h]	320	999	834
RRC-SRC-Exp [h]	0	0	767
Sub total [h]	438	1182	1816
Total [h]	3604	2702	3916

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