6 - 1 Operation Status of HIRFL In 2016

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In 2016, HIRFL has 7 488 machine hours, including 616 h for the machine preparation and 994 h for the machine commissioning due to beam change, 228.5 h for equipment failure period, 5 439.5 h for experiment target time, 108 h for machine study. Several different operation modes are included, 2 437 h for the independent operation of SFC; 2 948 h for the combination operation of SFC+SSC; 462 h for the combination operation of SFC+CSRm; 1 641 h for operation of the combination of SFC+CSRm+CSRe; and 102 h for others.

In 2016, HIRFL provided 26 different types of heavy ion beams for various experiments, among which, 11 kinds of heavy ion beams with different energy were first time commissioned. The typical ion beams provided by HIRFL in 2016 are listed in Table 1.

Table 1 The typical ions beam provided by HIRFL in 2016.

Index	Beam	SFC		SSC		CSRm		CSRe
		Energy/(Mev/u)	Current/μA	Energy/(Mev/u)	Current/μA	Energy/(Mev/u)	Current/μA	Current/μA
1	$^{112}Sn^{26+/35+}$	3.7	2			400.88	1 100	RNB
* 2	$^{32}S^{9+}$	5.4	1.4					
* 3	$^{32}S^{9+}$	4	1.2					
* 4	$^{4}He^{1+}$	4	2.5					
5	$^{86}Kr^{17+/26+}$	2.345	2	25	0.06			
6	$^{209}Bi^{31+}$	0.911	0.14	9.5	0.015			
7	$^{12}C^{4+/6+}$	7	2.6	80.55	0.1			
8	$^{12}C^{3+}$	4.2	4			122	200	140
* 9	$^{16}O^{5+/8+}$	5.361	2.5	60	0.4			
* 10	$^{40}Ar^{11+}$	4.71	4					
11	$^{16}O^{6+}$	7.723	2					
12	$^{56}Fe^{17+}$	6.3	1.2					
13	$^{12}C^{4+/6+}$	7	4			7	50	
14	$^{40}Ar^{12+/17+}$	6.17	3	70	0.3			
15	$^{209}Bi^{31+}$	0.911	0.2	9.5	0.03			
16	$^{58}Ni^{19+/25+}$	6.17	1.7	70	0.05			
* 17	$^{36}Ar^{11+}$	5.4	2					
18	$^{16}O^{6+}$	7.99	1					
19	$^{12}C^{4+/6+}$	5.361	2.4	60	0.3			
20	$^{32}S^{9+}$	4	1.4					
21	$^{18}O^{6+/8+}$	6.17	4.8	70	0.45			
22	$^{20}Ne^{7+}$	6.17	2					
23	$^{58}Ni^{19+/25+}$	6.17	0.7	70	0.05			
24	$^{209}Bi^{31+}$	0.911	0.1	9.5	0.01			
* 25	$^{40}Ar^{15+}$	7	1.2			320	300∼600	
*26	$^{40}Ar^{14+}$	7	1.5			389.2	300∼500	RNB

*First time commission.

In 2016, different types of experiment were committed on HIRFL including 3 178 h of beam time for nuclear and atomic physics experiments; 238.5 h for biological experiments; 2 023 h for research of material irradiation and single event effect; 108 h for the machine study. Table 2 shows summary of the HIRFL operation time.

The highlights of the operation in 2016 are summarized as follows:

1) The electron cooling with pulsed electron beam was realized in CSRm for the first time worldwide. The preliminary beam experiment revealed the relations of cooling effects with electron current modulation frequency, pulse length and peak current, *etc.*

2) Beam experiments has been committed to improve isochronousity of CSRe at double TOF mass spectrometry mode.

Table 2 Distribution of HIRFL operation time in 2016.

Operation time distribution	Time/h	Percentage/%
Total operation time	7 488	100
Failure time	228.5	3.0
Preparation of beam	1 610	21.5
Other time	102	1.4
Target beam time	5 547.5	74.1
Nuclear physics	3 178	57.3
Irradiation	2 023	36.5
Biophysics	238.5	4.3
Machine study	108	1.9

3) Newly installed profile monitor (PM) was used to measure the vertical profile in CSRm for the first time.

4) The sensitivity of current detector at SSC was improved with a factor of 3, for the beneficial of accelerating of very heavy and weak current beam.

5) The fraction of beam time on target reached 74.1% of the operation time, broke the historical record of HIRFL.

6) SECRAL-II as a backup of present superconducting ECR ion source(SECRAL) passed process testing, keeps the state of art ECR ion source technology, will be a very good support for LEAF and HIAF projects. Some breakthrough in technologies of high current, high charge state, high power very heavy ion sources; including movable 3-electrode extraction for high extraction efficiency of extra-heavy ion beam, All-aluminum thin-walled plasma arc-chamber for creation of high charge state ion beam at high power, *etc.*

7) The pre-research of injection laser induced plasma with high-charge-state ions into ECR ion source finished successfully. The problem of ion beam creation of the refractory metal with melting point above 2 000 ℃ was basically solved.

8) Realizing of space vector PWM rectifier technology, and success of breakthrough in matrix converter technology. The frequency of fast feedback arbitrary-waveform quadrupole power supply reached 800 Hz.

9) Commitment of field testing for superconducting magnet of Penning ion trap.

10) New PS control system for CSR based on EPICS.

11) Commissioning and researching of drift tube linac DTL1 in SSC-Linac injector project, with $^{16}O^{5+}$ beam.

6 - 2 New RF System for RFQ Accelerator of C-ADS Injector II

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According to the design for C-ADS, the failure time are limit strictly by several hours in one year. And previous tetrode amplifier has some problems, such as high sparking risk in input/output cavity, running pressure while high intensity current due to no circulator and so on. However, since the dissipated power in RFQ cavity is very high, the Solid-State Amplifier (SSA) must be designed to output very high power in spite of two couplers feeding power into resonator. Finally, two new 80 kW SSAs were decided to develop considering the power margin and beam loading, which were fabricated by two different manufacturers in order to verify the technologies on high power combining.

Two power sources deliver the power to the cavity other than tetrode amplifier, which split the power into two couplers from one power source. According to the design of RFQ, new parameters of SSAs were decided and optimized, and every module in it must stand hot swapping (insertion and extraction without ceasing electricity) and a long-term full power reflection. The two sets of SSA as shown in Fig. 1 were installed in April of 2016, and the preliminary tests were completed while SSAs connected with dummy load. As examples, the measured harmonic and noise suppression were presented in Fig. 2, which agrees with the designed ones. The (a) and (b) mean −37.2 dB and −71 dB results from one SSA, and (c) and (d) show −42.29 dB and −61 dB results of the other one.

So far, two sets of SSA appear to meet the requirements of C-ADS operation, the new features of full-power reflection test (shown in Fig. 3) and a long-term stability were proved to be better than previous tetrode one.