COMMISSIONING OF KIRAMS-30 CYCLOTRON FOR NUCLEAR SCIENCE RESEARCH

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Abstract

Recently, the needs to develop new cyclotron for radioisotope production and neutron generation are increasing in Korea. KIRAMS-30 cyclotron has developed from April 2005 to March 2007. It was installed at ARTI/KAERI in December 2006 and beam development was continued up to July 2007. The first production beams were irradiated at internal target. KIRAMS-30 magnet has 4 sectors and RF frequency is 63.96 MHz. It can be designed to reduce the power consumption of the system. Careful shimming operation was done for getting the value of exact designed magnet field. In addition, to obtain the higher intensity of beams, optimized inflector has been designed and manufactured.

INTRODUCTION

We have used 50MeV Cyclotron for neutron treatment and radioisotope development from 1986 at KIRAMS.

After 1990's research concern with radiation technology including medical applications has been growing in Korea. Early cancer diagnosis through the PET-scanner has been brought to public attention by KIRAM cyclotron. As a part of Regional Cyclotron Installation Project, KIRAMS-13 cyclotrons and [^{18}F]FDG production modules are being installed at Regional Cyclotron Centres in Korea. The KIRAMS-13 cyclotron is a compact low energy cyclotron developed by KIRAMS in 2002. It produces different short-lived radioisotopes, such as [^{18}F], [^{11}C], [^{13}N] and [^{15}O]. Also gamma emitters as [^{201}Tl], [^{67}Ga], [^{123}I] are increasing demand steadily. The KIRAMS-30 cyclotron has been developed for the production of gamma emitting radio nuclides and fast neutron generation from 2004 to 2006. It was installed at Advanced Radiation Technology Institute in Jeongup-city of Korea in 2006. KIRAMS-30 is typical 30 MeV high intensity of beam cyclotron. There are 4 purposes of construction. The first purpose is to develop of new radionuclides and labelling compounds. The second purpose is to generate fast neutrons with Beryllium target. The 3rd purpose is material science and nuclear technology research in biology, physics, and chemistry. And also it will be used in industries including radioisotopes mass productions and radiopharmaceuticals.

Beam commissioning is executing at internal with pop-up probe. The expected proton beam current of for KIRAMS-30 cyclotron is 500 μA at 30 MeV.

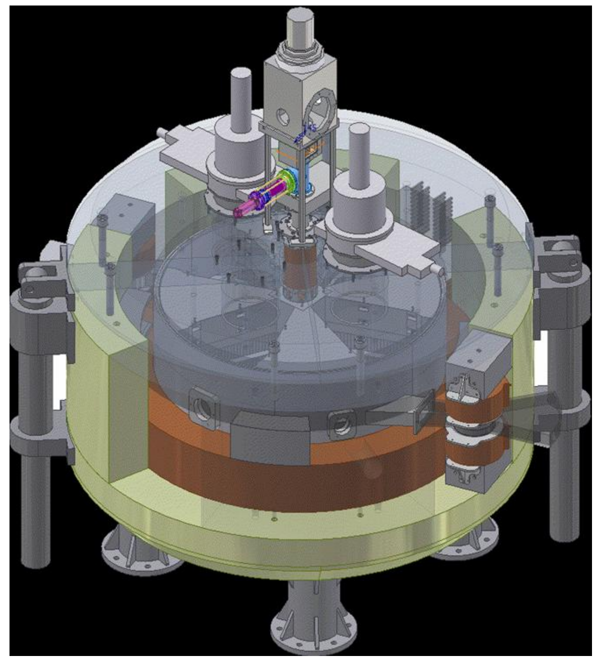


Figure 1: Overview of KIRAMS-30.

GENERAL DESCRIPTION OF KIRAMS-30

KIRAMS-30 cyclotron is typical 3rd generation cyclotron magnet that is pillbox shaped magnets used in the superconducting cyclotrons. The magnet system makes isochronous magnetic field. The central magnetic field is 1.05 Tesla. It has 4 sector magnets which weight is 50 ton. Magnet is surrounded with yoke steel completely and has relatively deep valleys and hills. For reducing power consumption of magnet we designed strong vertical focussing considerably. Magnet is working about 11.27 kW. The multi-cusp ion source can be produced maximum 10 mA of H- ions. For the higher efficiency of beam injection by external ion source, optimized injection beam lines including spiral inflector, double gap buncher, Solenoid-Quadrupole-Quadrupole and spiral inflector focusing units have been carefully designed.. The buncher makes the beam denser and SQQ matches the beam shape with the spiral inflector. The beam injected into the cyclotron starts acceleration with the fixed RF and fixed magnetic field. The RF frequency is 63.96 MHz and harmonic numbers are 4. The 50 kW RF power amplifier transfers the RF power signal to the RF resonance structure of cyclotron through a capacitive coupler. The beam accelerated to 15-30 MeV is extracted by movable carbon stripper foil. The extracted beam is delivered to targets through the beam-lines system. The beam line system keeps up the beam quality. All the cyclotron and beam-line system have vacuum and cooling system. The vacuum level of main vacuum chamber is about 1.2x10^{-7} mbar. General specifications of KIRAMS-30 is shown at table 1.

Table 1: General Specifications of KIRAMS-30.

Ion Source	Ion Source	Multi-cusp type
	Max. Extracted Beam Current	10 mA
	Type of Extracted Ions	Negative Hydrogen
Injection system		Buncher, Faraday Cup, SQQ, Spiral Inflector
Extracted beam	Extraction	Stripper Carbon Foil
	Type of extracted ions	proton
	Extraction Beam Current	Max. 500 μA
	Extraction Beam Energy	15 MeV-30 MeV
	No. of extraction port	2
	No. of Beam lines	4
	Beam irradiation	Dual available
RF system	RF frequency/ Harmonic Number	63.96 MHz / 4
	No. of Dee / Dee angular Width	2 / 39 deg
	Amplifier power	50 kW
Magnet system	Pole/Extraction Radius/Height/Diameter	0.81 / 0.736 /1.94 /2.7 m
	Hill Angle	48 deg
	Center field	1.05 T
	radial/vertical tunes	1.1/0.75
	Operating Coil Current / Consumption Power	131 A / 11.2 kW
Beam Transport Line	Length	6 m
	components	Steering, Faraday Cup, triplet Quadruples, AC magnet

MAGNET SYSTEM

Magnetic field characteristics

We designed KIRAMS-30 magnet with Opera 3-D^{R}. The magnetic field characteristics are shown figure 1. Maximum magnetic field intensity is 1.92 T at hill gap and 0.25 T, minimum magnetic field intensity, at valley gap at 45 cm from centre

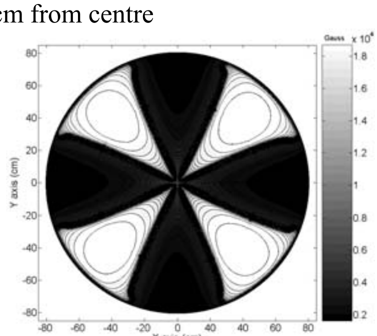
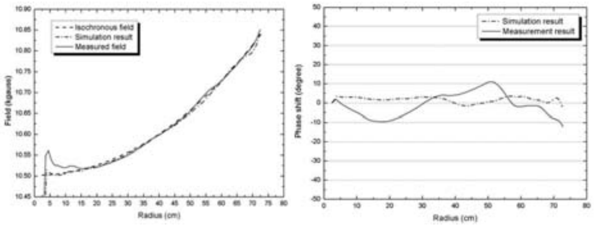


Figure 2: Magnetic field characteristics of KIRAMS-30.

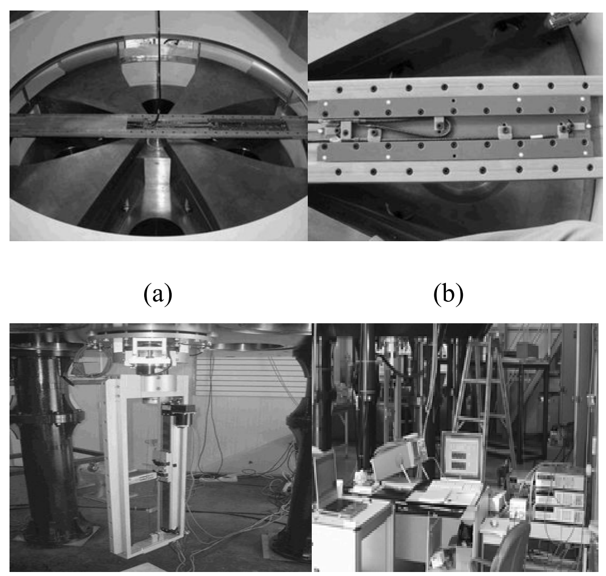


(a) (b)

Figure 3: Average magnetic field distribution graph (a) and accumulated phase error (b).

Magnetic field measurement

We have developed magnetic field measurement instrument. It consisted of the rotational stepping motor for the Hall probe rotation, the linear motor, two Hall probes, and DVMs etc. The two Hall probes were calibrated with the NMR tesla-meter when they were chosen to reduce absolute field error. The field measurement covered whole pole area with the resolution of 10 mm in radial direction and 0.04 degree in azimuthal direction, respectively. It takes only 75 minutes for full measurement. The measurement instrument was controlled by a computer with the program written Lab-View.



(a) (b)

(c) (d)

Figure 4: Magnetic field measurement instrument; Rotary table with Hall probe (a) (b), Motor driver (c) Data acquisition and control electronics (d).

Assembly and operation of magnet

We used S10C for magnet material. Hollow magnet coils wound 22 layers and 16 turns as double pancake shape. After assembly magnet diameter is 2.7 m, weight is 50 ton and height is 1.44 m. It is composed of upper and lower yoke, poles, spiral hills and coils. Operation currents are 130 A with 86 V. Power consumption is about 11.2 kW for coil.

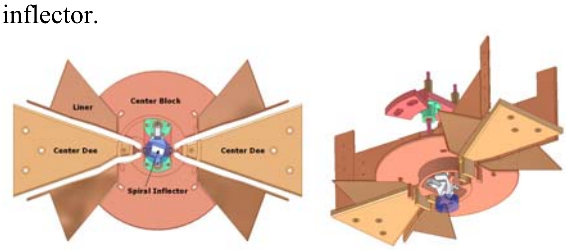
(a) (b)

Figure 5: Photograph of operation after assembly (a) and opening upper yoke with oil pressure cylinder (b).

CENTRAL REGION

In the case of a static magnetic field and time-varying electric field, the relative positions of the gaps can be centred with the best applying in the theory of horizontal motion of ions. It allows acquiring the higher intensity of external beams.

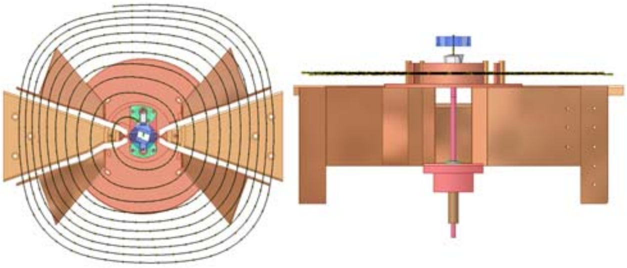
Spiral inflector convert axial direction to horizontal direction for ion beams without energy varying. We designed considerably about arrival beams at median plane safely, minimization of beam loss, and beam matching between central region and after through spiral inflector.



(a) (b)

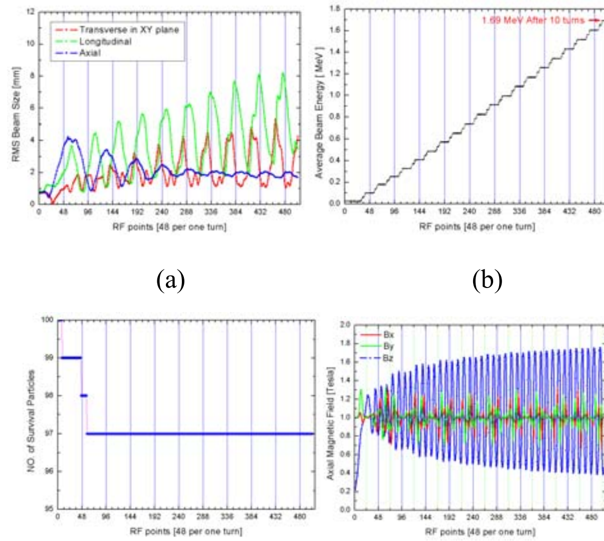
Figure 6: Central region of KIRAMS-30 (a) 3-D view of central region and spiral inflector (b).

Figure 7(a) and 7(b) show the horizontal and vertical trajectories of the ions respectively. The RF phase acceptance in horizontal and vertical motion is about 54 degrees from 271 to 325.



(a) (b)

Figure 7: Horizontal trajectories of the ions (a) Vertical trajectories of the ions (b).



(a) (b)

(c) (d)

Figure 8: Change of beam size (a), energy increment of per turns (b), particle loss (c) and magnetic field (d).

Figure 8 is shown beam size change, energy increment per turns and particles loss. We can find beam focussing is enough at axial direction near central region. Beam is losing 3 % before 1.25 turns.

ION SOURCE AND INJECTION SYSTEM

Ion Source

Ion source is volume type DC multi-cusp source for negative hydrogen generation. After filled hydrogen gas filament applied 230A currents generate thermal electron. Electrons are collided with hydrogen at cusp body. Negative hydrogen is dense between plasma boundary and cusp wall. We used cusp body designed by TRIUMF.

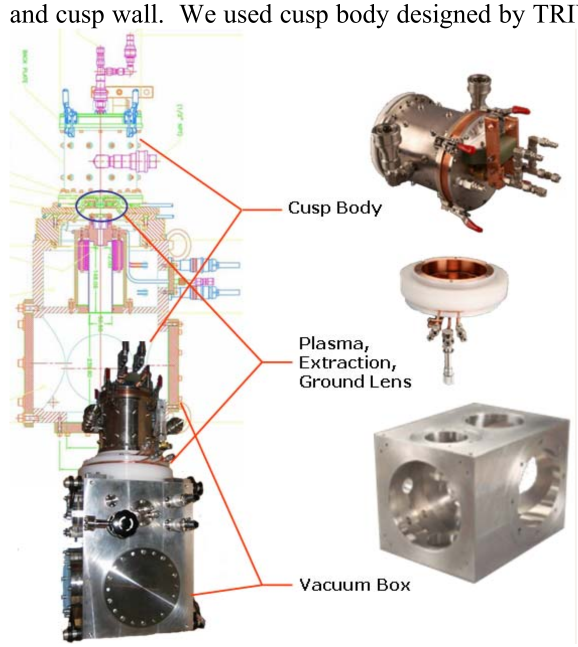


Figure 9: DC multi-cusp source.

Table 2 is shown operation conditions by extraction of beams from multi-cusp ion source. Arc voltage is maintaining 100 V. Arc current is set 2 A, 3 A by adjustment of filament current automatically.

Table 2: Operating conditions for multi-cusp ion source.

Extraction	1 mA	2 mA	5 mA	10 mA
Arc (V/A)	100/2	100/3	100/8	100/20.5
Plasma (V/A)	1.7/1.2	2.0/1.8	3.1/4.8	3.6/11.1
Extractor (kV/mA)	1.1/5	1.3/10	2.5/19	3.3/45
Filament(V/A)	3/170-280	3/170-280	3/180-290	3/170-280
Hydrogen(sccm)	3.5	4.0	8.5	14
Bias (kV/mA)	25/2.5	25/5.0	25/12.5	25/21.3

Injection System

Injection system is composed of buncher, faraday cup, solenoid lens, and Q-pole doublet lens.

Negative hydrogen ion beams extracted from ion source are injected through SQQ(solenoid + Q doublet) at the hole of centre of upper magnet yoke axially. They are inserted to DC spiral inflector by axial direction and come out by horizontal direction at median plane.

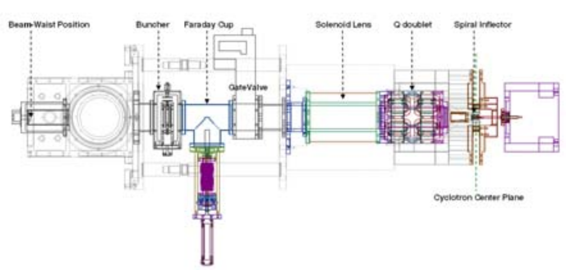


Figure 10: KIRAMS-30 Injection system.

Buncher

Double gap buncher is used for beam bunching. Double gap buncher system is composed of high frequency matching circuit, RF signal generator, RF amplifier, double gap buncher, and frequency tuner. RF power is transferred with direct coupling type. Maximum voltage difference at the centre pole of buncher is 200 V. Gap distance is 18.7 mm. It is used 500 ㎛ wire at the centre pole and inner side of ground pole.

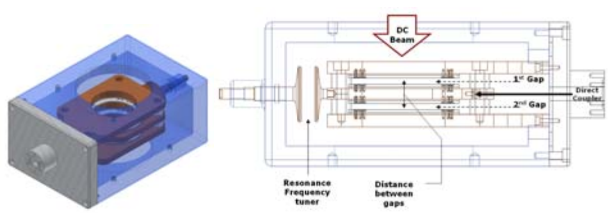


Figure 11: Double gap buncher.

SQQ(Solenoid-Q pole doublet) beam focussing unit

Solenoid with 1.321 kG is gently sloping of magnetic field variation at the hole of upper magnet yoke. Beam size and transverse distribution can be adjusted at the entrance of spiral inflector with Q-pole doublet lens. Magnetic gradient 0.297 T/m, 0.921 T/m in Q-pole can be adjusted beam size to 4.2 ㎜ x 2.4 ㎜ before inflector.

Table 3: SQQ specifications and operation parameters.

	Solenoid Lens	QX	QY
Dimension [㎜]	ID110, OD190, H252	ID80, OD100, H50	ID80, OD100, H50
Beam Tube ID.[㎜]	90	70	70
		Distance between Qs : 62 ㎜	
Layers x spirals	6x40	4x6	4x6
No. of coils	1	4	4
Conductor [㎜]	5.5x5.5, ID3.6	2x2	2x2
Conductor length [m]	120	20	20
OP/Max. Current [A]	165/200	20/50	20/50
OP/Max. Voltage [V]	21/50	2/10	2/10
OP. Power [kW]	3.4	0.04	0.04
Cooling flow rate [ℓ/min]	1.4	0	0
Operating field [kG]	1.321	0.297	0.921
OP.Field gradient [T/m]		0.2965 T/m	0.9207 T/m

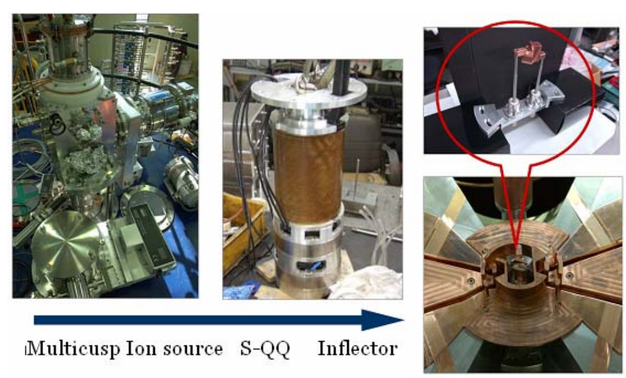


Figure 12: Manufactured photograph of Ion source, S-QQ, and spiral inflector.

RF SYSTEM

RF system is for energy getting of negative hydrogen ion beam. All components of RF system are made with oxygen free copper considering electrical conductance and out-gassing in vacuum chamber. RF resonator and Dee are designed with Micro Wave Studio (MWS/ CST). Resonance frequency is 63.96 MHz. It has 4^{th} harmonics. Resonance Q value is 7525. Two 39° Dees are located in two valleys. Dee voltage is relatively high 55 kV compared with commercial cyclotrons.

When we designed and manufactured RF system considering arcing, multipacting, mechanical stability, cooling problems by RF power transfer, simple maintenance and cost effectiveness.

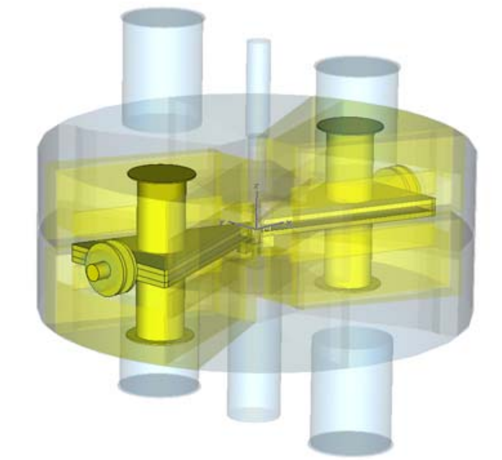


Figure 13: Designed Dees and cavities.

Figure 14: Manufactured Dees and cavities.

RF auto-tuning system

RF auto-tuning system tune RF frequency automatically changed by heat coming, mechanical variation, etc. This system has auto mode operation by phase differences and manual operation mode. It is composed of RF signal processing unit, controller for fine tuning. RF signal processing unit controls input signal voltage with 3 dB attenuator received by RF pick-up.

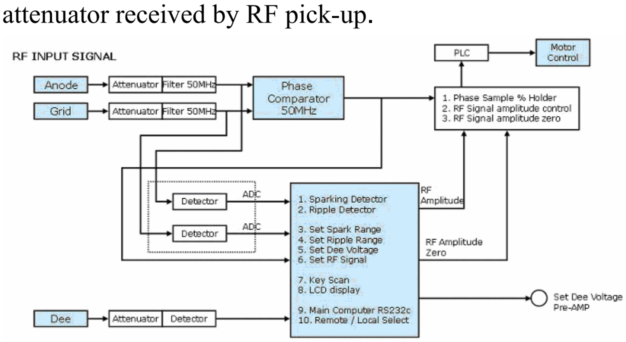


Figure 15: RF auto-tuning system.

EXTRACTION SYSTEM

KIRAMS-30 cyclotron can be extracted proton beams in range of 15-30 MeV. Extraction beam energy range can be controlled to be changed distance of carbon foil position. We can get dual beams simultaneously by stripper arrangement of 180 degree.

Table 4: Extraction position of 15 – 30 MeV.

Energy (MeV)	15	20	25	30
Extraction position (R ㎝, θ ˚)	54.73, 52.5	62.93, 53.4	69.85, 54.3	76.06, 55.2

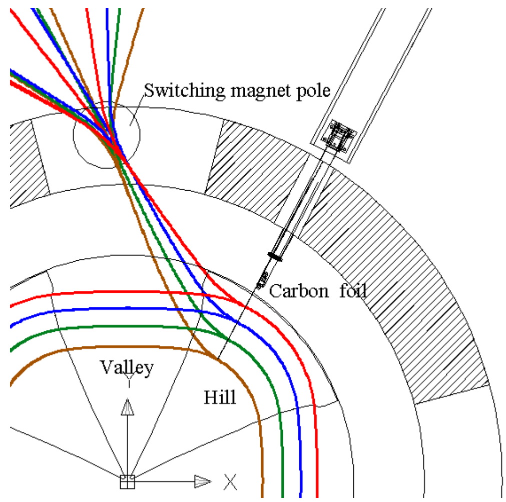


Figure 16 : Extraction position of 15 – 30 MeV.

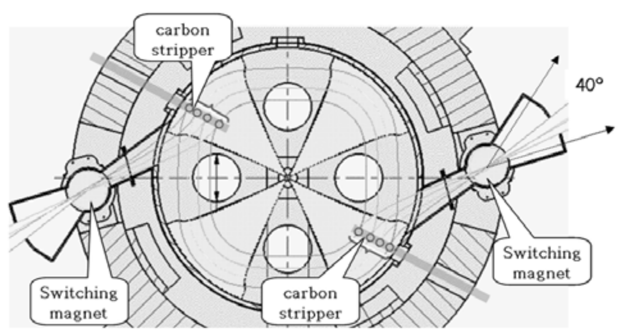


Figure 17: Dual beam extraction.

CONTROL SYSTEM

KIRAMS-30 control system consists of 9 sub-systems (magnet, RF system, ion source. vacuum, cooling, beam diagnosis, and transport system). Main computer controls all subsystems. We used cFP[R](Compact Field Point/ National Instrument Co.) for interface boards with main computer with LabView[R].

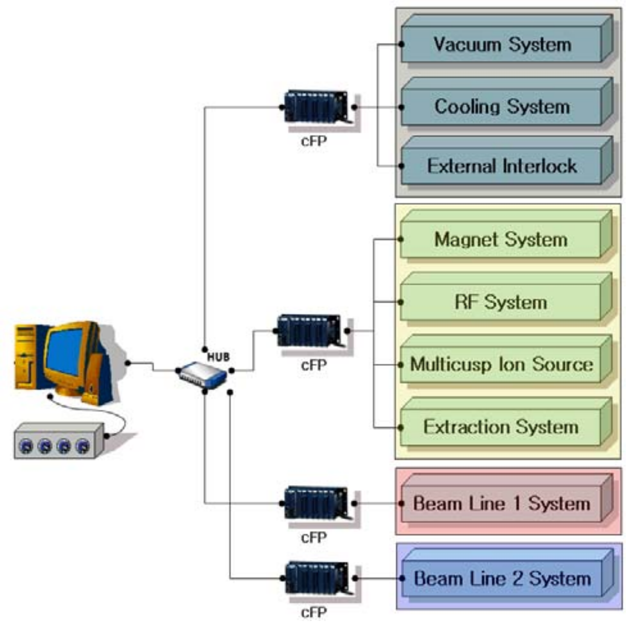


Figure 18: KIRAMS-30 control system.

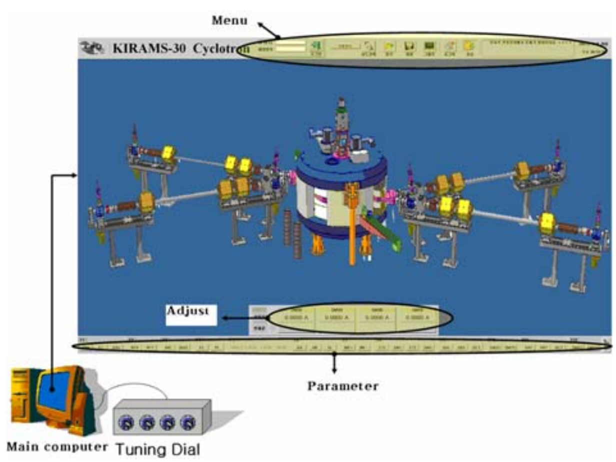


Figure 19: User interface for control program.

OPERATION RESULTS AND DISCUSSION

Installation of KIRAMS-30 was finished on March 2007. From March to June we were concentrated on getting maximum beam intensities from multi-cusp ion source. We got 8 mA from ion source.

KIRAMS-30 was measured negative hydrogen beam at 1.5 MeV position because it was installed at temporal building of ARTI in Jeongup-city. We got radiation approval at 1.5 MeV beam bombarding from Korea Institute of Nuclear Safety. Next October KIRAMS-30 will move to regular building with radiation shielding fully. Cyclotron building is constructing now.

We developed pop-up beam probe for measurement of negative hydrogen beam. Beam current is detected at copper foil of probe end. Copper foil should be stood over 200μA during beam current measurement. Now we are getting 70 μA beam current. We have found some alignment problems at injection lines. For getting the higher intensities of beam we are adjusting alignment of injection system and spiral inflector position carefully. Final goal beam current of KIRAMS-30 is about 500 μA.

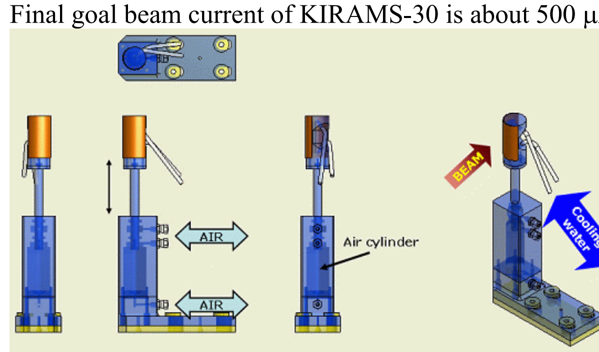


Figure 20: Pop-up probe.

Figure 21: KIRAMS-30 cyclotron.

CONCLUSION

KIRAMS-30 cyclotron has been developed for nuclear technology development and research.

Design feature of KIRAMS-30 has optimization, low power consumptions, and cost effectiveness realization.

After movement at regular building we get 30 MeV energy and 500 μA maximum currents.

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