PROGRESS ON CONSTRUCTION OF CYCIAE-100

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Abstract

Beijing Radioactive Ion-beam Facility (BRIF) is being built at China Institute of Atomic Energy (CIAE). As a driving accelerator for ion beam production, CYCIAE-100 will provide proton beam of 75MeV～100MeV with an intensity of 200μA～500μA. At present, the design for each system has been accomplished and an overall progress has been made for the CYCIAE-100 project. The manufacture of the main magnet has entered into the final assembly stage. Two main magnet coils have been completed, two 100kW RF amplifiers are tested with full output power, the main vacuum chamber and main magnet lift system will be completed soon. The construction designs and suppliers surveys for other systems are finished and ready for purchase. Some key design and technology experiments are in process and significant results have been achieved in verifications. The "Central Region Model Test Stand for High Intensity Cyclotron Development" (CYCIAE-CRM) has successfully passed the formal certification held by the competent authorities. A full scale experimental RF cavity has been fabricated, on which the frequency and Q value measured coincide well with the numerically calculation. The verification test of vacuum cryo-panel structure has provided valuable information to cryo-panel structure design. The key technical problems related to CYCIAE-100 project are being solved along with the progress.

INTRODUCTION

The Beijing Radioactive Ion-beam Facility (BRIF) project being built at China Institute of Atomic Energy (CIAE) is planned for productions of intense proton and Radioactive Ion Beam (RIB) used in fundamental, applied researches and medical isotope production. In this project, a 100MeV H- cyclotron is selected as the driving accelerator to operate together with an existing HI-13 Tandem.

As a key component of BRIF project, CYCIAE-100 will provide a 75MeV - 100MeV, 200μA - 500μA proton beam. Its functions are mainly for a RIB facility, physics experiments, applied science and isotope production research. Its preliminary designs and related earlier stage work were presented at ICCAs in Tokyo of 2004 and in Italy of 2007 respectively.

The preliminary designs for all sub-systems of CYCIAE-100 were accomplished in 2006，followed by the detailed design and construction between 2007 and 2009. An overall progress has been made in design and manufacture and important results have been achieved for CRM and high power experimental RF cavity in 2009 [1]. Figure 1 shows the sketch map of CYCIAE-100.

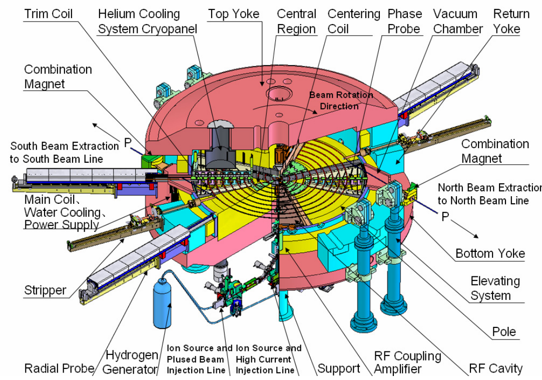

Fig. 1 Sketch map of the major parts of CYCIAE-100.

THE PROGRESS OF MAIN SYSTEMS

A lot of challenges were accepted during the period of fabrications and constructions. A significant progress has been achieved up to now. Some important results will be introduced briefly below. The latest progress of CYCIAE-100 made in recent years will be presented, among which are the final engineering design features, key component fabrication progress, construction status and their pretest specifications.

Main Magnet system

Design Optimization

Due to its large size (6.2m in diameter) and heavy weight (120 ton for one piece), the structure optimization of the main magnet is necessary before stepping into engineering process. While keeping the structure as far as convenient for fabrication, many factors, e.g. the weight, magnetic field force, vacuum force, should be considered together to evaluate its deformations at operating condition after commissioning. As a consequence, some major revisions have been made:

The top/bottom yokes adopts an uneven-height structure instead so that the magnet deformation along radius induced by the atmospheric pressure after pumping can be reduced by 41.26% compared to that of an even-height structure in previous design.

The asymmetric shimming bars are designed in a way that the limited space is best used at the outer radium (R>1200mm) between the shimming bar and the RF cavity. This design eliminates the influence from the coupling resonance on the working path at high energy end in the tune diagram. This kind of asymmetric shimming bar design is a standby solution in case the BH curve of steel is not as good as the designed specification.

Two sets of special measuring tools for main magnet are designed. One is used to measure the angle of the sector, and the other is used to measure the varying gap surface of the sector. Besides, a set of installation tool is specially designed for the shimming bar installation.

Magnet Materials Obtaining

The rough machining steel for the magnet sectors was produced by INDUSTEEL in France and transported to CIAE in April of 2008. It is consisting of 4 roughcasts for 8 sectors with a total weight of about 140 tons. The sampling and repeat test results showed that both the magnetic properties and chemical composition could satisfy the technical requirements.

For the top/bottom and return yokes, considering the large dimensions and existing industrial capablility, it has been decided to use cast steel.

The fabrication contract was signed with CITIC Heavy Machinery Co. LTD. in 2007. The casting of return yokes and experimental piece of the top/bottom yokes had been done by the end of 2007. The preliminary analysis result shows that the chemical composition of the molten steel meets the requirement of the designed specifications. All the fabrication work of the cast steel for the top/bottom yokes were accomplished in May of 2008 and the rough machining was accomplished by August.

The finished product of a top/bottom yoke weighs 129 tons with the actual molten steel of 280 tons. It is unprecedented in term of both scale and technical challenges of casting in the accelerator field and industrial capability. The finished product of each return yoke weighs 15 tons with the actual molten steel of 42 tons.

Following the completion of casting, nearly 400 samples were tested for chemical and magnetic properties under different situations including before and after the stress relief and magnetic property annealing, showing that the design requirement could be satisfied. Figure 2 shows the comparison of BH curves of the top/bottom yoke in different situations and the rough machining steel from France.

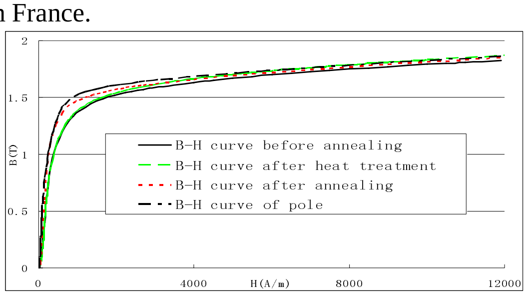

Fig.2 Measurement results of magnetic properties

The rough materials for magnet pole shimming bars and central cylinders are forged steel produced by Taiyuan Steel Company in Shanxi province, China.

Magnet machining and assembling

After the interface conditions related to the main magnet have been determined and the construction design for the fine machining of the major parts has been finished [2], the contract was signed with CITIC Heavy Machinery Co. LTD in January of 2009.

In 2009，the key parts of main magnet system were fabricated, including stress annealing of top/bottom yokes, ultrasonic flaw detection, fixture equipment machining, fine machining of top/bottom yokes, pre-fine machining of sector poles, return yokes, and shimming bars. Figure 3 shows one top yoke after pre-fine machining and the fabricated sector poles.

Fig. 3 One top yoke after pre-fine machining (left) and fabricated sector poles (right).

Up to now, all components of magnet have been fabricated. Vacuum checking for top/bottom yokes is undergoing. The magnet sectors and shimming bars have been installed together. The general installation of the whole magnet and fine adjusting the sector positions are the main tasks afterwards.

RF system

RF power source

The fabrication contract for two 100kW RF amplifiers of CYCIAE-100 was signed in 2007. By the end of June, 2008, the evaluation on the manufacturing solution to the contract was finished, entering into the fabrication stage. By the end of the year, the assembling of the driving amplifier in factory and on-site inspection has been accomplished, as seen in Figure 4.

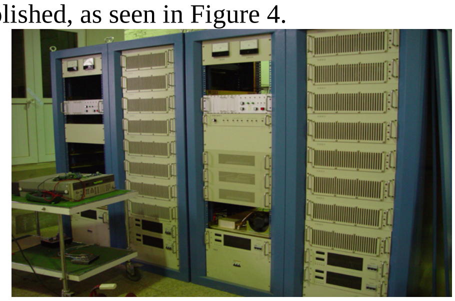

Fig. 4 The 6kW driving power amplifier and monitoring devices

All fabrications have been done in 2009. In August of 2009， the manufacture of RF power generators and transmission lines were finished. The installing and testing began in September. The check and acceptance of their specifications were completed on site in December, as shown in Figure 5. The two sets of RF power generators and transmission lines meet the design requirements both in output power, frequency and in stability, repeatability and control modes.

Fig.5 Acceptance of RF power generators and transmission lines

RF Resonance Cavity Design

Based on the preliminary design, the adjustment and optimization of RF cavity tip and Dee structure has been done and the mechanical design has been finished [3]. The RF power consumption and the numerical simulation of the temperature distribution on the cavity are calculated, and the related water cooling system is also designed. Figure 6 is the general schematics of RF cavity and the test RF cavity model installed.

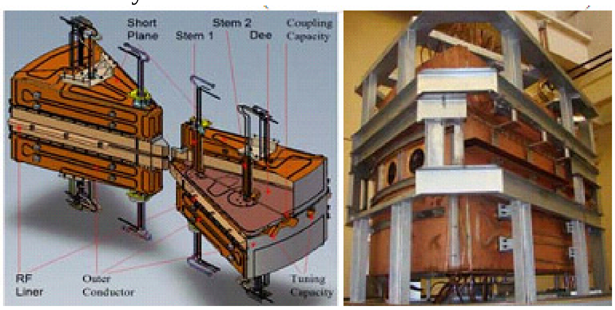

Fig.6 The schematics of RF cavity & test RF cavity model.

Main Coils System

In 2009，the construction contract for two main coils was signed with a factory in Shanghai. Meanwhile, special hanging tool used for main coil was designed. Aimed at high technical requirements with critical dimensions, the fabricating test and copper tube soldering test should be done before the formal fabricating begins.

In February of 2010, the resin pouring of two main coils was made and then the two large coils were transported to the magnet fabricating factory in Henan province for combining installation. Figure 7 shows the two completed coils on construction site.

Fig. 7 Two coils on construction site

Elevating system

Fig. 8 The components of elevating system.

The elevating system is designed to raise a weight of 180 tons with a height of 1500mm. After completing the design of both screw jacks and hydraulic elevating systems, the two solutions were compared and the 4-point hydraulic system was finally determined.

The construction contract was signed in 2009. Now the fabrication has been completed, and it will be transported to magnet manufacture factory for assembly and test with the magnet at the end of 2010. Figure 8 shows elevating system components test on construction site.

Magnetic Field Measurement System

The measurement of main magnet field is planned to be carried out under low vacuum condition in CYCIAE-100 [4]. Figure 9 shows the constructed magnetic field mapping system and 3 hall probes will rotate simultaneously with the beam. The position accuracy of the mapping system is less than 0.1mm in radius and less than 13 seconds in azimuth. At present, the fabrication of the system has been finished and is ready for the assembly and test.

In order to measure magnetic property for dipole, quadrupole, solenoid lens, ion source and switching magnet, etc., a high resolution three dimension locating platform is built at CIAE.

Fig. 9 The designed test stand of mapper.

Vacuum system

For CYCIAE-100, the vacuum of the main vacuum chamber should be better than 5×10^{-6} Pa. Considering all of the effects including the sector magnets, centering coils, beam diagnostic probes and beam extraction probes located inside the vacuum chamber, it is more difficult to obtain the required vacuum and the total pumping speed needed should be more than 140,000L/s based on outgassing load calculation.

Fig. 10 The vacuum chamber in machining process.

The final engineering design of vacuum system was fixed at end of 2009. The main vacuum chamber is a huge aluminum cylinder of 1.27m in height and 4.08m in inner diameter and the top/bottom yokes are functioning as its covers. The fabrication contract of main vacuum chamber was signed in January of 2010. Now the soldering and stress annealing of the vacuum chamber have been finished, and the fine machining is under way. Figure 10 shows the vacuum chamber in machining process.

Standard commercial pumps could not satisfy the vacuum demands, for which large cryopanel is the only solution. Short of relevant experiences, a test stand of cryopanel structure was designed and built. The test results obtained provide useful information for the final cyopanel system design. The detail of the test is given in the section of 3.3.

Injection and Extraction System

Injection System Optimizing and Experiment

The top/bottom yokes are of uneven height and the dimension of the magnet in the axial direction is increased. Based on the new structure of the magnet, the injection line was redesigned and the calculation for the optics matching was accomplished.

The fabrication and test on the H- ion source prototype have been finished. The result from the test stand shows that when the beam intensity is above 10mA, the normalized emittance of 80% beam is 0.45 mm-mrad.

Extraction System Optimizing and Experiment

The beam transfer matrix is calculated from the stripper to the combination magnet and the dispersion effects during the beam extraction are also studied through numerical tracking [5]. The hill gap of the combination magnet is increased from 60mm to 80mm.

Since the stripping probe is a crucial device for the extraction system, specific work on the physical design and mechanical structural design of the stripping probes has been carried out. Several schemes have been researched and compared. After repetitive discussions, it has been decided that the structure of a turnable stripper foil changing in the vacuum is applied in the final design.

The structure of stripper foil exchanger was built and tested, through which the problems related to its reliability were solved, as seen in Figure 11.

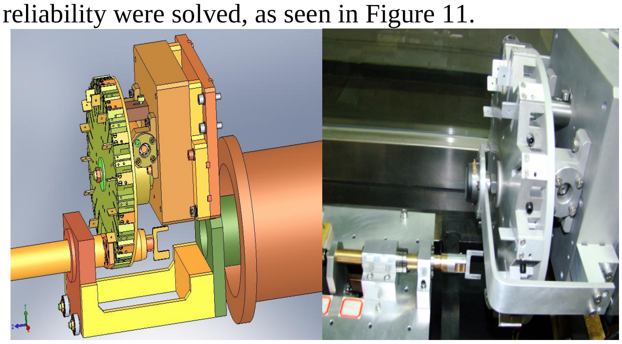

Fig. 11 The designed and real foil exchanger

Other Aspects

Beam Diagnostics System

The experimental study on the beam diagnostics system has been performed, including the data acquisition, transmission, processing, etc. The experiments on the DCCT, double wire scanner, emittance scanner have been done. The related design and fabrication has been finished as well.

The experimental phase probe, radius inserted probe, etc., have been built and tested at CRM. Their structures have been optimized and their technical feasibility has been verified through the test.

Dd26tement ose Monitoring and Safety Interlock System

The layout design of the devices for radiation monitoring and safety interlock has been completed. In the meantime, investigation on the measuring neutrons at wider energy range was done and research on fast electronics of γ detector was carried out.

The software flowchart was developed. The systematic software focuses on DSP program and its real time simulating environment was built. Purchase of the PMTs, GM tubes and PLC for radioactivity detection and control interlock is conducted. The experimental test on the preamplifier of the dose monitoring probe is under way.

Electricity and Power Supplyd26tement System

The schematic design for electricity and power supply system has been fixed. There are more than 100 power suppliers in total and can be divided into 3 types, most of which use numerical control. A new system for current stability calibration of the power suppliers has been built and tested.

In order to meet the magnetic mapping requirement, the main magnet power supply has been built with the specifications of 110A/286V in rated output and $\pm 1\times 10^{-5}$/8h in stability. The photo pictures of the power supply are shown in Figure 12.

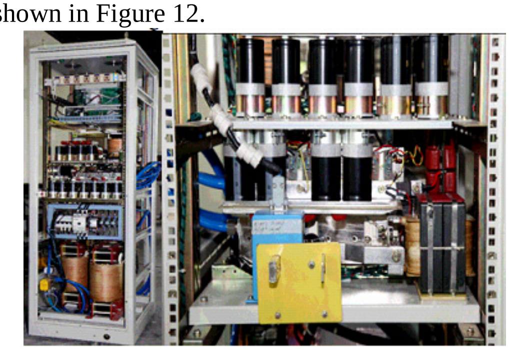

Fig. 12 Photos of main magnet power supply.

Computer Control System

EPICS system is chosen for CYCIAE-100. The control system is a middle scale, rich interlock system, which contains approximately 1,100DI/DO and 300 AI/AO process variables, distributed in several subsystems. Figure 13 shows the general control diagram of BRIF.

The control of various power supplies is a main task of control system, the digital RS-232/485 control interface and multi-port input/output controller have been selected. Recently, an embedded EPICS IOC on Moxa DA662 computer under MontaVista Linux operating system was developed and various tests have been performed.

For low level RF(LLRF) control research, date sampling program with multi-function used on master and slave computers was developed and verified at CRM.

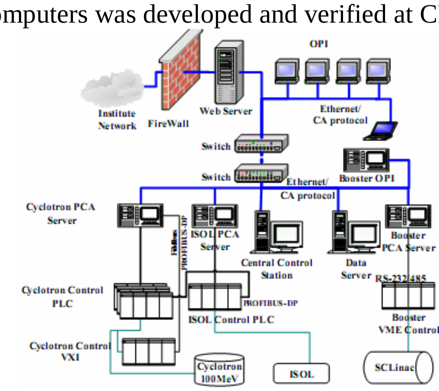

Fig. 13 General control diagram of BRIF

RESULTS OF THE KEY CERTIFICATION TESTS

Three key experimental verifications have been performed and significant progress has been achieved. They are Central Research Model (CRM), 1:1 RF Cavity Test, vacuum Cryo-panel Test.

Central Research Model

The central research model is to study the key technologies related to the CYCIAE-100 project. The model with a designed energy of 10MeV consists of all equipments of a compact cyclotron. As a comprehensive test platform, it is used to verify practically the beam dynamics calculations and the key equipments structure designs of the 100MeV machine.

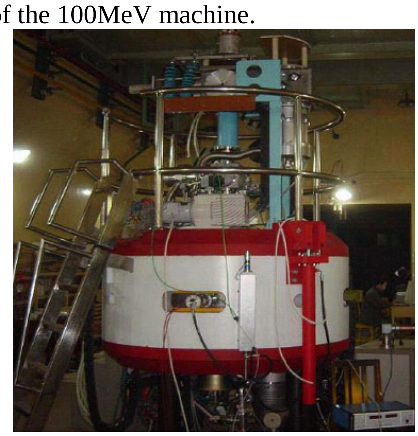

Fig. 14 Central research model

CRM has 4 straight sectors with angle of 54^{o} and the maximal filed of 1.75T. A 13.5kW RF amplifier drives two RF cavities with the frequency of 70.5MHz. CRM is installed in 2006 and 5.8μA beam on internal target was obtained in 2007.

In 2008, a significant progress was achieved after some improvements had been done. The internal beam intensity increased to 130μA and 5.8μA/10MeV beam was extracted [6].

In 2009, the beam specifications were upgraded further after some improvements were made. The internal beam current is up to 432μA and extraction current reaches 230μA under the condition of 64% RF duty ratio. The beam injection and acceleration efficiency is 17.7%, the 94.5% respectively, and the beam extraction efficiency is nearly 100%. Some typical beam test dada are shown in Table 1.

Table 1 Some typical beam test dada

year	Ccurrent of ion source	RF duty	Inter-current (buncher off)	Inter-current (buncher on)	Current extracted
2008	2.1mA	25%	28uA	48uA	5.8 uA
	2.1mA	70%		130uA	
2009	2.43mA	100%		32.6uA	
	2.43mA	64%			230uA

High Power RF Cavity Test

The purpose of building 1:1 scale model is to verify the final RF cavity design and to test if the key manufacture procedures are practical and reliable or not. Especially for large dimension and complicated structure of copper cavity, it is crucial how to solder and in the meantime to prevent from deformation and to keep the designed RF specifications even at high power conditions.

In 2009, 2 technological problems concerning soldering and form calibration were solved through many times of soldering experiments and equipment upgrading. So far the test RF cavity has been completed and installed. During the long period of production, useful experiences were accumulated. For example, the Dee plate welding has been done inside the furnace and heated under vacuum condition; Dee stems have got good quality through electro-beam welding, etc.

f=45.8MHz and Q=5000 come from the preliminary cold measurement at beginning. The Q value is increased to 9300 soon after polishing the cavity surface, adding contact spring sheets, necessary connectors, position tuning, etc.

Other parts, such as power coupling, frequency tuning, vacuum container are all set in place. The high RF power has been fed into the test cavity. The test stand was shown in Figure 15.

Fig. 15 High power RF cavity test stand.

Vacuum Cryo-panel test

In order to verify the cryopanel structure used to CYCOAE-100, a test stand was designed and built. A plug-in cryopump with a pumping speed of 15000 L/s was designed and tested [7]. The plug-in cryopump is mainly used to determine several key parameters, including its pumping speed, ultimate pressure, temperature distribution, etc.

Figure 16 shows the structure and appearance of the test cryopanel. It consists of half-chevron baffles, a shield, the cryopanel, a flange, an adapter, and two GM refrigerators. Gas particles are adsorbed onto the cryopanel surface and kept at a low temperature by the refrigerators. To reduce the heat load on the cryopanel, half-chevron baffle are used to block some of the incoming radiation. The entire system is surrounded with a cylindrical shield. The cryopanel heat load calculations, including the shield and baffle, have been conducted.

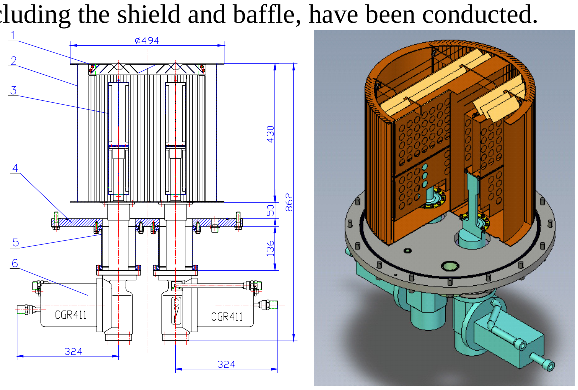

Fig.16 Structure of test Cryopanel

The design parameters and experimental results are compared and coincided well. With only the turbo-molecular pump (80L/s) operating, a pressure of 3.2×10^{-4} Pa was reached. After coating shield and baffle, the pressure dropped to 5.8×10^{-6} Pa with refrigerator after 3.5 hours of operation. The refrigerator had a power of 83W/80K at the first stage and 7.5W/20K at the second stage. The temperature on shield top reached 67.7K, and 19K on second stage of cold head. The maximum tested pumping speed was 15250L/s. Figure 17 shows the Cryopanel Test Stand.

Fig.17 Cryopanel Test Stand

The test results have provided valuable information to cryo-panel physics design and set up the foundation for cryo-panel structure design of CYCIAE-100.

CONCLUSION AND NEW SCHEDULE OF CYCIAE-100 PROJECT

In conclusion, a remarkable progress has been achieved in the past few years in the design, construction and experimental verification of CYCIAE-100. Most of the key equipments for this machine have been fabricated or will be finished by the end of this year.

Nevertheless, the schedule of BRIF as a whole project has to be postponed for some budget reasons. According to the new schedule, the construction of building for CYCIAE-100 will start in the first quarter of next year. The whole project will be completed with the first beam at the end of 2013 or the beginning of 2014.

The general outline of the new schedule is planned as follows: ①The temporary installing and testing site will be ready at end of this year. ②The fabrications of sub-systems of CYCIAE-100 are fully carried out and will be finished one by one from now on till the next year. ③In the first quarter of 2012, all equipments will be moved to the permanent positions in the CYCIAE-100 building; after final mapping of the field and installation of the relevant equipments, the sub-systems will be tested at normal conditions. ④Beam tuning is hopefully to start in the first quarter of 2013. ⑤Beam specifications are to meet required standards at end of 2013.

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