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INTERNATIONAL STANDARD

Fixed energy high intensity proton cyclotron within the energy range of 10 MeV to less than 30 MeV

colour inside

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CONTENTS

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FIXED ENERGY HIGH INTENSITY PROTON CYCLOTRON WITHIN THE ENERGY RANGE OF 10 MeV TO LESS THAN 30 MeV

FOREWORD

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IEC 63175 has been prepared by IEC technical committee 45: Nuclear instrumentation. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
45/930/FDIS	45/932/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Particle accelerators have a wide application in the field of nuclear physics, radiation hardening, accelerator-driven energy system (nuclear reactor), and of course radioisotopes production, etc.. Proton cyclotron is one particular class of particle accelerators used for example for the acceleration of negative hydrogen ions.

This document specifies the performance and safety requirements, structure, technical requirements, test methods, identification, packing, transportation, storage and accompanying documents for proton cyclotrons.

Annex A and Annex B are both informative.

FIXED ENERGY HIGH INTENSITY PROTON CYCLOTRON WITHIN THE ENERGY RANGE OF 10 MeV TO LESS THAN 30 MeV

1 Scope

This document is applicable to hydrogen ion H^- acceleration proton cyclotrons with one or more fixed energies within the range of 10 MeV to less than 30 MeV and a beam intensity equal to or greater than 300 μA.

This document specifies the performance and safety requirements, structure, technical requirements, test methods, identification, packing, transportation, storage and accompanying documents for such cyclotrons.

This type of cyclotrons is intended for industrial use, including medical isotope and neutron production. Therapeutic medical applications are excluded from the scope of this document.

This document is intended for manufacturers of high intensity proton cyclotron within the energy range of 10 MeV to less than 30 MeV, and responsible organizations where such cyclotrons are installed.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60038:2009, *IEC standard voltages*

IEC 60204-1:2016, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60243-1:2013, *Electric strength of insulating materials – Test methods – Part 1: Tests at power frequencies*

IEC 60364-1:2005, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 60364-5-51:2005, *Electrical installations of buildings – Part 5-51: Selection and erection of electrical equipment – Common rules*

IEC 61000-4-4:2012, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-5:2014, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-6-2:2016, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity standard for industrial environments*

IEC 61000-6-4:2018, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

IEC 61010-1:2010, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*
IEC 61010-1:2010/AMD1:2016

IEC 61140:2016, *Protection against electric shock – Common aspects for installation and equipment*

IEC 62305 (all parts), *Protection against lighting*

ISO/IEC Guide 37:2012, *Instructions for use of products by consumers*

ISO 780:2015, *Packaging – Distribution packaging – Graphical symbols for handling and storage of packages*

ISO 8573-1:2010, *Compressed air – Part 1: Contaminants and purity classes*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online Browsing Platform: available at http://www.iso.org/obp

3.1
cyclotron
device that uses static magnetic field to make charged particles to whirl and to be repeatedly accelerated by radio frequency electric field with fixed frequency

3.2
beam energy
kinetic energy of charged particles in a beam through a cyclotron device

3.3
beam intensity
total charge of charged particles passing through a section in unit time

3.4
phase shift
difference between the phase of charged particle cyclotron motion and radio frequency voltage at the gap crossing

Note 1 to entry: The expression of phase shift is shown in Formula (B.2).

3.5
unloaded quality factor
quality factor when the resonator is not connected to any external circuit (no load)

Note 1 to entry: When the resonator is in a stable resonant state, the unloaded quality factor Q_0 is defined as:

$$Q_0 = 2\pi \times \frac{Total\ energy\ storage\ in\ resonator}{Energy\ dissipation\ of\ resonator\ in\ one\ cycle} \tag{1}$$

Note 2 to entry: One example of actual measurement and calculation methods for unloaded quality factor is shown in Annex A.

4 Cyclotron composition and operational conditions

4.1 Composition

Generally, the cyclotron consists of the following components:

a) ion source and injection system;

b) magnet system;

c) radio frequency system;

d) vacuum system;

e) extraction system;

f) power supply system;

g) control system;

h) interlock system for radiation safety;

i) beam monitoring system;

j) water cooling system and pneumatic system.

4.2 Normal operating conditions

4.2.1 Environmental requirements

Environmental requirements are as follows:

a) ambient temperature: 15 °C to 35 °C;

b) relative humidity: 35 % to 65 %, no condensation;

c) indoor and outdoor pressure difference: maintain sufficient negative pressure;

d) control room: ambient temperature is 15 °C to 26 °C with relative humidity lower than 60 % and no condensation.

4.2.2 Electricity requirements

Electrical requirements for cyclotron power supply environment are as follows:

a) power supply: a three-phase five-wire (TN-S, IEC 60364-1:2005) or a three-phase four-wire (TN-C-S, IEC 60364-1:2005) AC system. In case of a four-wire system, the cyclotron has to be cabled as a single consumer with five-wire after the first power entry panel;

b) voltage: listed in Table 1 of IEC 60038:2009, the supply voltage shall not differ from the nominal voltage of the system by more than ±10 %;

c) frequency: 50/60 Hz ±1 Hz.

4.2.3 Compressed air

Instructions for use shall specify the operating condition range for compressed air supply (ISO 8573-1:2010 [1.4.1]).

4.2.4 Nitrogen

In case nitrogen is used for venting the cyclotron main tank when the cyclotron is under maintenance, instructions for use shall specify the operating conditions.

4.2.5 Lightning and electric shock protection

Lightning and electric shock protection in the cyclotron workplace shall be designed according to IEC 62305.

4.2.6 Ion source media

Cyclotron uses hydrogen for the ion source. Instructions for use shall specify the operating condition range of hydrogen for the ion source.

5 Technical requirements

5.1 Warning signs

Warning signs shall follow the requirements in 16.2 of IEC 60204-1:2016 or applicable requirements which may differ between nations or organizations.

5.2 Performance index

High intensity cyclotron accelerates the negative hydrogen ions, and the ion beam quality shall satisfy the following performance indexes:

a) beam nominal energy: beam nominal energy value shall be specified in the instructions for use;

b) beam intensity: the sum of beam intensity in all directions shall be specified in the instructions for use;

c) beam spot size: the diameter of beam spot which contains 95 % of the total beam at the extraction foil shall be equal to or less than 50 % of the magnetic gap; magnetic gap here means the sector gap at the extraction point;

d) comprehensive beam efficiency: equal to or greater than 5 % for external ion source.

5.3 Main subsystems performance index

5.3.1 Ion source

Beam quality (intensity and emittance) provided from the ion source shall be sufficient based on the efficiency defined in 5.2.

5.3.2 Radio frequency system

Under the condition of fixed working frequency, radio frequency system shall satisfy:

a) frequency relative instability: less than or equal to 1×10^{-6};

b) voltage relative instability of Dee plate: less than or equal to $\pm 5 \times 10^{-3}$.

5.3.3 Vacuum system

Provided the vacuum gauge is properly positioned in the vacuum chamber, non-hydrogen gas load working pressure and hydrogen gas load working pressure of the vacuum chamber should be lower than 3×10^{-4} Pa and 8×10^{-4} Pa respectively to avoid beam loss.

If the vacuum system is restarted after venting the cyclotron main chamber with dry nitrogen, the above pre-working pressure requirements shall be within the time guided by instruction manual and no more than 6 h.

5.3.4 Control system

The basic functions of the control system shall include:

a) cyclotron start-up and shut-down by automatic program or manual control;
b) setting, adjustment and display of the main operating parameters of the cyclotron;
c) display and alarm of operation state and fault of the cyclotron in case of deviation from its normal operation;
d) logbook, real time chart and data logging function;
e) acknowledge by the operator of alarms and interlock before allowing the beam to restart after clearance of the alarm or interlock condition.

5.3.5 Interlock system for radiation safety

The purpose of the cyclotron safety interlock system is to ensure personal safety of the staff and avoid exposure to ionizing radiation. When the cyclotron hall is occupied, the cyclotron cannot be switched on. No one is allowed to enter the cyclotron hall when the cyclotron is in operation. The manufacturer of the cyclotron shall provide an interface allowing the reception of interlock signals from the responsible organization. The signals shall shut down the beam during irradiation and shall prevent start of irradiation if hazardous condition exist. The instruction for use shall describe the characteristics of the signals and the number of inputs/outputs provided. The responsible organization where the cyclotron is installed shall provide a building interlock system for radiation safety that includes:

a) Interlock with the operation of the protective door: when the protective door is open, the cyclotron is not allowed to supply beam.
b) Interlock with the onsite dose monitoring device: the system monitors the dose (including prompt gamma and neutron) in the cyclotron hall, and the interlock system shall alarm and cut off the beam supply when emergency occurs.

   NOTE 1 Onsite dose monitoring device is under the responsibility of the responsible organization.

c) Interlock with the indicator and warning device: the system shall monitor the residual gamma dose rate in the cyclotron hall when the cyclotron is shut down. When the monitored dose rate exceeds the prescribed value, the instrument signal indicator shall be triggered, and the light alarm signal shall be sent out. If the residual gamma dose rate does not exceed the prescribed value, the green light is displayed. Otherwise, red light flickers.

   NOTE 2 Indicator and warning device is under the responsibility of the responsible organization.

d) Interlock with emergency stop buttons: once the emergency stop button is triggered, the cyclotron shall stop the beam supply immediately.
e) Interlock with the cyclotron operation indicator: when the cyclotron is in operation, the indicator light installed outside the shield gate shall be clear and bright to indicate that "the cyclotron is in operation".
f) Interlock with the Last-Man-Out system: cyclotron hall and target room should be installed with Last-Man-Out system and the cyclotron operation can be started only after activating the Last-Man-Out system successively.

   NOTE 3 Last-Man-Out system is under the responsibility of the responsible organization.

5.3.6 Water cooling system

The manufacturer of the cyclotron shall specify the requirements of the interface to the water cooling system heat exchanger of the responsible organization in the instruction for use. The cyclotron water cooling system shall be a closed-loop system with monitoring of conductivity, temperature and flow. The closed-loop water cooling system of the cyclotron shall satisfy:

a) water quality: deionized water with conductivity less than 0,5 μS/cm;

b) water temperature: 20 °C to 35 °C (outlet of heat exchanger);

NOTE Preferred temperature range is 20 °C to 30 °C.

c) pressure: 0,4 to 0,8 MPa (outlet of pumping unit).

5.3.7 Stripping extraction efficiency

Stripping extraction efficiency shall be not less than 99 %.

5.4 Electrical safety

5.4.1 Protective grounding

The cyclotron is classified as Class I equipment (IEC 61140:2016) requiring protection against electrical shock, which shall be equipped with protective conductor terminal. The resistance between the protective conductor terminal and each accessible part of the cyclotron device for which protective bonding is specified shall not exceed 0,1 Ω (IEC 61010-1:2010).

5.4.2 Insulation resistance

The insulation resistance between wires (including phase line and neutral line) and ground of each independent electrical device of the cyclotron shall be not less than 1 MΩ when the test voltage (DC average) reaches to 1 000 V (IEC 60204-1:2016).

5.4.3 Dielectric strength

Electrical equipment with electrical grounding shall tolerate the dielectric strength testing of 2 000 V (AC RMS or DC average) with no breakdown and no repeated arcing during the test (IEC 60243-1:2013).

5.4.4 Touch current

Under normal operation conditions, the leakage current between the accessible parts of the cyclotron device and the protective conductor terminal shall not exceed 0,5 mA for sinusoidal waveforms (IEC 61010-1:2010).

5.5 Radiation safety

The radiation dose rate and surface contamination levels shall meet the national radiation protection regulations.

5.6 EMC

5.6.1 Surge immunity

The test method of surge immunity is referred to IEC 61000-4-5:2014, and the test result shall meet the requirement of surge immunity in IEC 61000-4-5:2014.

5.6.2 EFT immunity

The test method of EFT immunity is referred to IEC 61000-4-4:2012, and the test result shall meet the requirement of EFT immunity in IEC 61000-4-4:2012.

5.6.3 Emission

The test method of emission is referred to IEC 61000-6-4:2018, and the test result shall meet the requirement of emission in IEC 61000-6-4:2018.

5.6.4 Immunity

The test method of immunity is referred to IEC 61000-6-2:2016, and the test result shall meet the requirement of immunity in IEC 61000-6-2:2016.

5.7 Operation

Instruction for use shall contain appropriate information to allow safe startup and normal operation of the cyclotron. As specified in individual contracts, instruction for use may contain additional information to meet the needs of the user.

Instructions for use shall contain appropriate information to allow safe startup and normal operation of the cyclotron. As specified in individual contracts, instructions for use may contain additional information to meet the needs of the end user.

6 Test methods

6.1 General requirements

6.1.1 Test environmental conditions

Environmental conditions of the test shall be agreed between the manufacturer and the user. If no special requirements are mentioned in the individual contract, the test shall be carried out under the environmental conditions of Table 1 (IEC 60364-5-51:2005).

Table 1 – Environmental conditions of the test

No.	Code	Environmental parameters	Reference value	Range
1	AB5 [a]	Ambient temperature	25 °C	15 °C to 35 °C [a]
2	AB5 [b]	Relative humidity	-	35 % to 65 % [b]
3	AC1	Altitude	-	≤ 2 000 m
4	AM-3-2	Power supply voltage (AC)	- [c]	± 10 %
5	AM-5	Power supply frequency (AC)	50/60 Hz	50/60 Hz ± 1 Hz
6	AM1-2	Power supply waveform distortion (AC)	sine wave	Total waveform distortion less than 5 %
7	AM-8-1	Radiated magnetic fields	free space	≤ 3 A/m

[a] The ambient temperature in AB5 condition ranges from 5 °C to 40 °C. The test range of ambient temperature in Table 1 is revised as 15 °C to 35 °C for safe operation and stable performance.

[b] The relative humidity in AB5 condition ranges from 5 % to 85 %. The test range of relative humidity in Table 1 is revised as 35 % to 65 % to avoid potential safety problems for normal operation.

[c] The nominal power supply voltage differs in various countries. But the voltage shall not differ from the nominal voltage by more than ±10 %.

6.1.2 Test equipment

Instruments and equipment for the test shall be calibrated according to the quality assurance instructions for them. The accuracy of the measuring instruments shall meet the requirements of the accuracy of the measured parameters.

6.2 Warning signs check

Conformity is checked by inspection to demonstrate that the requirements of 5.1 are satisfied.

6.3 Performance test

6.3.1 Beam nominal energy

Tesla meter with probe accuracy of 0,1 ‰ is used to measure the field map and hence the average magnetic field of closed orbit passing extraction position is obtained. The beam nominal energy is calculated using Formula (2).

$$E \approx m_0 c^2 \left[\sqrt{1 + \frac{q^2 c^2}{\left(m_0 c^2\right)^2} \times \left(\overline{B} \times \overline{r}\right)^2} - 1 \right] \approx 938,27 \left[\sqrt{1 + \left(\overline{B} \times \overline{r}\right)^2 / 9,78} - 1 \right] \qquad (2)$$

where:

E is the beam nominal energy, in MeV;

m_0 is the mass of proton, in kg;

c is the light speed in vacuum, in m/s;

q is the charge of proton, in Coulombs (C);

$\overline{B}$ is the average magnetic field of closed orbit passing extraction position, in Teslas (T), and one example of measurement methods is referred to Annex B;

$\overline{r}$ is the average radius of closed orbit passing extraction position, in m.

Calculation results shall meet the requirements of 5.2a). The procedure described above is one of the methods for evaluating beam nominal energy.

6.3.2 Beam intensity

Beam intensity shall be measured with appropriate instrumentation, such as stripping foil, and the results shall meet the requirements of 5.2b).

6.3.3 Beam spot size

Beam cross-section distribution is measured by appropriate instrumentation, such as a wire scanning device, at the extraction exit of the beam or in a position that allow a measurement representative of the extraction exit of the beam, as shown in Figure 1. The maximum beam current I_{max} can be obtained. The distance between the two positions with 0,1 I_{max}, which are at the edge of beam cross-section, is defined as diameter of beam spot, as shown in Figure 2. The measurement results shall meet the requirements of 5.2c). The procedure described above is one of the methods for beam spot diameter measurement.

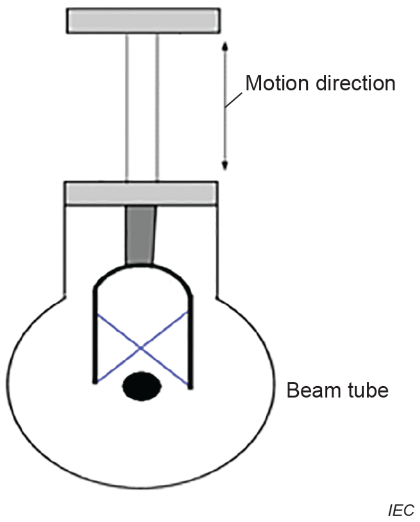

Figure 1 – Schematic diagram of beam spot diameter test

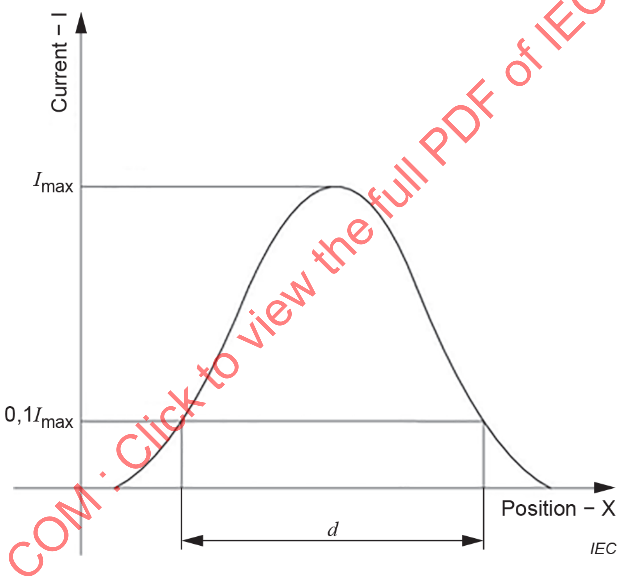

Figure 2 – Schematic diagram of beam spot diameter test result

6.3.4 Comprehensive beam efficiency

Comprehensive beam efficiency η_t is defined as the ratio of total extracted beam intensity I_3 to the beam intensity from the ion source I_1 which are measured by micro ampere ammeter and Faraday cup or other adequate instruments. This beam efficiency is shown in Formula (3).

$$\eta_t = I_3 / I_1 \times 100\% \tag{3}$$

where:

η_t is the comprehensive beam efficiency;

I_1 is the beam intensity from the ion source, in micro amperes (μA);

I_3 is the total beam intensity at the extraction exit of the cyclotron, in micro amperes (μA).

The calculation results shall meet the requirements of 5.2d).

6.4 Main subsystem performance test

6.4.1 Ion source beam intensity

Negative hydrogen ion beam of the ion source is measured by Faraday cup and micro ampere ammeter or other equivalent instrumentation. The measurement results shall meet the requirements of 5.3.1.

6.4.2 Radio frequency system

6.4.2.1 Frequency relative instability

Frequency meter is used to measure the frequency relative instability of RF system. The continuous measurement lasts at least 30 min and the frequency data shall contain at least 65 data points. The frequency relative instability of RF system λ is defined as the ratio of the difference between max frequency $f_{\max}$ and min frequency $f_{\min}$ to the average frequency f_{aver}, which is shown in Formula (4).

$$\lambda = (f_{\max} - f_{\min}) / f_{aver} \times 100\% \tag{4}$$

where:

λ is the frequency relative instability;

$f_{\max}$ is the maximum frequency, in megahertz (MHz);

$f_{\min}$ is the minimum frequency, in megahertz (MHz);

f_{aver} is the average frequency, in megahertz (MHz).

The results shall meet the requirements of 5.3.2a).

6.4.2.2 Voltage relative instability of D shape acceleration electrode

The measurement of RF amplitude should be performed with a cavity pick-up. The continuous measurement lasts 30 min and the voltage data shall contain at least 65 data points. The voltage relative instability of D shape acceleration electrode τ is defined as the ratio of the difference between maximum of the pick-up voltage $U_{\max}$ and minimum of the pick-up voltage $U_{\min}$ to the average pick-up voltage U_{aver}, which is shown in Formula (5).

$$\tau = (U_{\max} - U_{\min}) / U_{aver} \times 100\% \tag{5}$$

where:

τ is the voltage relative instability;

$U_{\max}$ is the maximum pick-up voltage, in kilovolts (kV);

$U_{\min}$ is the minimum pick-up voltage, in kilovolts (kV);

U_{aver} is the average pick-up voltage, in kilovolts (kV).

The results shall meet the requirements of 5.3.2b). The procedure described above is one of the methods for voltage relative instability measurement.

6.4.3 Vacuum system

Vacuum of the main vacuum chamber is measured with a gauge capable to measure high vacuum. The measurement results shall meet the requirements of 5.3.3.

If the vacuum system is restarted after venting the cyclotron main tank with dry nitrogen, the time of achieving static vacuum shall meet the requirements of 5.3.3.

6.4.4 Control system

6.4.4.1 Startup and shutdown test: according to the startup and shutdown procedures specified in the product instruction manual, the cyclotron startup and shutdown is demonstrated. The test result shall meet the requirements of 5.3.4a).

6.4.4.2 Function test of the setting, adjusting and displaying of the cyclotron main parameters: according to the product instructions, the tests of the setting, adjusting and displaying of the main parameters are mainly focused on the vacuum system, cooling system, pneumatic system, radio frequency system and power supply system (ion source power supply, magnet power supply and so on). The test result shall meet the requirements of 5.3.4b).

6.4.4.3 Test of cyclotron operation status, fault display and alarm: under the condition of cyclotron normal operation, visual inspection method is applied to inspect the display function of each subsystem's working state. Under the fault condition, the visual inspection method is applied to inspect the display and alarm function of the system. The results shall meet the requirements of 5.3.4c).

6.4.5 Interlock system for radiation safety

6.4.5.1 Test of interlock with the protection door: when the cyclotron is in operation, simulate the protection door switch to open and observe whether the cyclotron stops the beam. The result shall meet the requirement of 5.3.5a).

6.4.5.2 Test of interlock with onsite dose monitoring device: preset the protection threshold of onsite dose monitoring device. When the dose rate exceeds a preset threshold value and the signal representing emergency triggers, check whether the system has alarmed or closed the cyclotron automatically. The results shall meet the requirement of 5.3.5b).

6.4.5.3 Test of interlock with signal indicator and warning device: adjust the threshold of dose rate monitor, check whether the indicator signal could be triggered and the light alarm signal could be sent out, and inspect the colour change of warning device.

The test results mentioned above shall meet the requirements of 5.3.5c).

6.4.5.4 Emergency shutdown test: when the emergency stop button is pressed, the cyclotron shall trigger the interlock operation of stopping radio frequency system, ion source and inserting beam blocking target. The test result shall meet the requirement of 5.3.5d).

6.4.5.5 Test of interlock with signal indicator: when the cyclotron is in operation, the "cyclotron operation indicator" installed on the outside of the protection door shall be clear and bright. The test result shall meet the requirements of 5.3.5e).

6.4.5.6 Test of interlock with Last-Man-Out system: if the Last-Man-Out system is not triggered, the inflector voltage should be removed and the RF signal of low-level RF system shall be disabled. The test result shall meet the requirements of 5.3.5f).

6.4.6 Water cooling system

Conductance meter is used to measure the conductivity of cooling water. The temperature of cooling water is measured by temperature controller. The pressure of cooling water is measured by pressure gauge. The results shall meet the requirements of 5.3.6.

6.4.7 Stripping extraction efficiency

Beam intensity I_2 (electrons) on the stripping foil is measured with micro ampere meter. The extracted beam intensity I_3 (protons), which hits on the target or probe at cyclotron extraction exit, is measured with Faraday cup and micro ampere meter. The stripping extraction efficiency η_{ex} is defined as the ratio of I_3 to $I_2/2$, which is shown in Formula (6):

$$\eta_{ex} = \left(\frac{I_3}{I_2/2}\right) \times 100\% \tag{6}$$

where:

η_{ex} is the stripping extraction efficiency;

I_2 is the beam intensity (electrons) on the stripping foil, in micro amperes (μA);

I_3 is the beam intensity (protons) at the extraction exit of the cyclotron, in micro amperes (μA).

The calculation results shall meet the requirements of 5.3.7. The procedure described above is one of the methods for evaluating stripping extraction efficiency. According to local regulation requirements, the measurement of the beam extraction efficiency might be needed to satisfy national and local licensing agencies' requirements.

6.5 Electrical safety

6.5.1 Protective grounding

Grounding resistance test equipment is used to measure the resistance between the protective conductor terminal and each accessible part of the cyclotron device for which protective bonding is specified. The test current is determined by 6.5.1.3 of IEC 61010-1:2010. The result shall meet the requirements of 5.4.1.

6.5.2 Insulation resistance

Insulation resistance meter is used to test insulation resistance between wires (including phase line and neutral line) and ground of each independent electrical part of the equipment. The test voltage is 1 000 V (IEC 60204-1:2016). This measurement needs to disconnect the phase line, neutral line and protective earth wire from the power supply. The result shall meet the requirements of 5.4.2

6.5.3 Dielectric strength

Test voltage shall be gradually increased to 2 000 V in 10 s, and maintained for 1 min (IEC 60243-1:2013). The test results shall meet the requirements of 5.4.3.

6.5.4 Touch current

According to IEC 61010-1:2010, 2 kΩ resistor is placed in parallel on the AC or DC voltmeter to measure the voltage between the accessible parts of the cyclotron device and protective conductor terminal under normal operation conditions of the cyclotron. The result shall comply with the requirements of 5.4.4.

6.6 Radiation safety

The test results shall meet the requirements of 5.5.

6.7 Operation test

The results of safe startup and normal operation test shall meet the requirements of 5.7.

7 Inspection rules

7.1 Summary

Cyclotron inspection is divided into type inspection and delivery inspection.

Type inspection shall be carried out in the following circumstances:

a) New products or transferred products;

b) When assessing the impacts, referring to a major change of structure, material, process and so on, on the product performance after the formal production;

c) When a major difference between the delivery inspection result and the last type inspection result occurs;

d) When local agency or authority requires for the type inspection.

7.2 Inspection items

Inspection items are shown in Table 2. The inspection shall be carried out in the order of Table 2. When needed, the order of some inspection items can be adjusted and some inspection items can be combined and tested.

Table 2 – Inspection items of 10 MeV to less than 30 MeV cyclotron

No.	Items	Type inspection	Delivery inspection	Technical requirements	Inspection method
1	Warning signs	▲	▲	5.1	6.2
2	Overall performance index: beam energy	△	△	5.2a)	6.3.1
3	Overall performance index: beam intensity	▲	▲	5.2b)	6.3.2
4	Overall performance index: diameter of beam spot	△	△	5.2c)	6.3.3
5	Overall performance index: comprehensive beam efficiency	▲	▲	5.2d)	6.3.4
6	Ion source	▲	△	5.3.1	6.4.1
7	Radio frequency system: frequency relative instability	▲	△	5.3.2a)	6.4.2.1
8	Radio frequency system: voltage relative instability of D shape acceleration electrode	▲	△	5.3.2b)	6.4.2.2
9	Vacuum system	▲	▲	5.3.3	6.4.3
10	Control system	▲	▲	5.3.4	6.4.4
11	Interlock system for radiation safety	▲	▲	5.3.5	6.4.5
12	Water cooling system	▲	△	5.3.6	6.4.6
13	Stripping extraction efficiency	▲	△	5.3.7	6.4.7
14	Electrical safety: protective grounding	▲	△	5.4.1	6.5.1
15	Electrical safety: insulation resistance	▲	△	5.4.2	6.5.2

No.	Items	Type inspection	Delivery inspection	Technical requirements	Inspection method
16	Electrical safety: dielectric strength	▲	△	5.4.3	6.5.3
17	Electrical safety: touch current	▲	△	5.4.4	6.5.4
18	EMC: Surge immunity	▲	△	5.6.1	5.6.1
19	EMC: EFT immunity	▲	△	5.6.2	5.6.2
20	EMC: emission	▲	△	5.6.3	5.6.3
21	EMC: immunity	▲	△	5.6.4	5.6.4
22	Operation	△	△	5.7	6.7
▲ for the required items. △ for optional items.					

7.3 Criterion rule

7.3.1 Products passing the inspection items in Table 2 during either type of inspection shall be the qualified products.

7.3.2 Defective items shall be repaired or replaced by the manufacturer, and a new inspection shall be carried out.

8 Signage, packing, transportation, storage and accompanying documents

8.1 Signage

8.1.1 Cyclotron signs

Cyclotrons shall be marked with legible permanent sign or signs in a suitable position. The sign shall include:

a) Manufacturer's name;

b) Cyclotron name and model;

c) Serial number and date of manufacture;

d) Product standard number.

8.1.2 Labels

All measuring meters, operating switches, buttons, indicator lights in the cyclotron system shall be labelled.

8.2 Packing

8.2.1 Cyclotrons shall be dispensed in crates, and the box shall contain the detailed packing list. Crates shall provide measures against rain, moisture, and shock. Components are fixed in the box and adequate soft material is used to avoid loose and rubbing.

8.2.2 Fragile parts shall be in separate boxes specially designed to ensure that they will not be damaged during transport.

8.2.3 Packaging marks shall comply with the relevant requirements in ISO 780:2015.

8.3 Transportation

8.3.1 Packaged equipment or components shall allow their transportation by automobiles, trains and ships.