Best® Cyclotron Systems

Compact Stripping Extractor for 70 MeV Cyclotron

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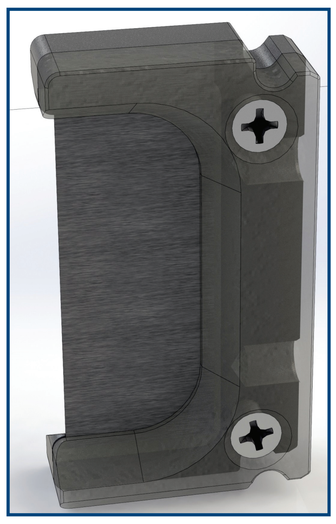
SUMMARY

Beam extraction from 70 MeV cyclotron is achieved by stripping method using two opposite extractors. The main characteristics are: extracted energy range 35 to 70 MeV protons and intensity per side of 0 to 100% of the total accelerated beam of up to 700 μA.

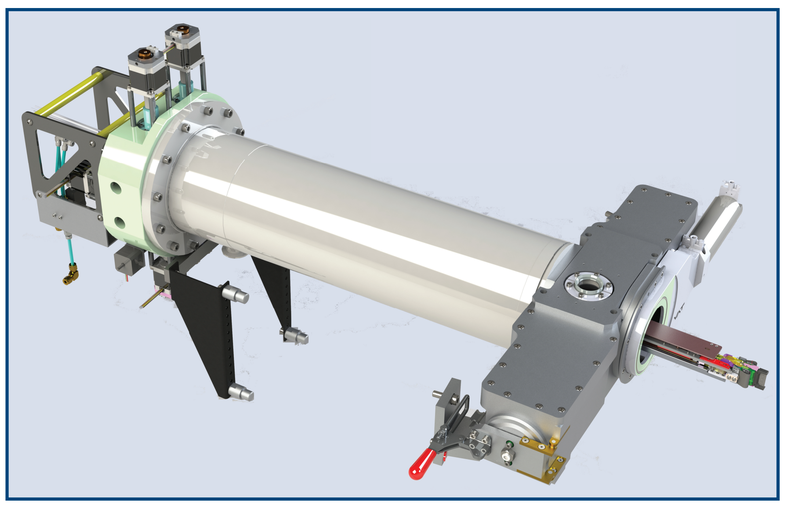
Each extractor has a cartridge with 22 foils that can be used in any order by taking one foil holder at a time while maintaining the vacuum and magnetic field. The foil holder is a graphite frame that can be fitted with a graphite foil of various thicknesses.

The construction of the extractor is modular in terms of functionality and service characteristics.



Extractor's components:

1. **Vacuum Box and Tube** — Offers reliable repositioning of the insertable internal mechanism and foil holder cartridge support. It also has a side cartridge door to facilitate the cartridge replacement.
2. **Cartridge Support Mechanism** — Resides inside the vacuum box between the main magnet coils and moves the cartridge in retracted or foil exchange positions.
3. **Insertable Mechanism** — Handles and positions the foil holders from the cartridge pocket to the extraction position in the cyclotron. It can be easily removed from the vacuum tube in case of service or replacement.



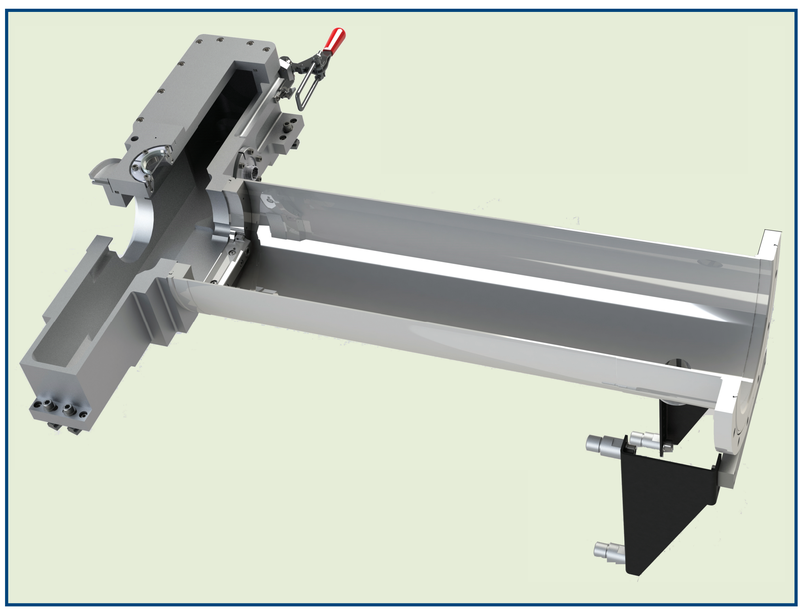
4. **Control Hardware & Software** — Commonly available industrial PLCs and motor drivers integrated within B70p Cyclotron Control system allows the operator to monitor the extractor status and control its functions.

DETAILED FUNCTIONAL & GEOMETRICAL PARAMETERS OF EXTRACTOR MODULES

VACUUM BOX & TUBE

The vacuum box resides in the space between the cyclotron main magnet coils, vacuum wall and return yoke.

Connection to the cyclotron vacuum wall is achieved using a "D-Clamp" proprietary quick disconnect device that also accommodates an insertable gate valve. The same D-Clamp is used throughout various beam line segments for simple gate-valve insertion. In this case the opening in the gate valve and vacuum wall has a 102 mm diameter.



The vacuum box cover allows access for installation of the cartridge support mechanism and also has a viewport.

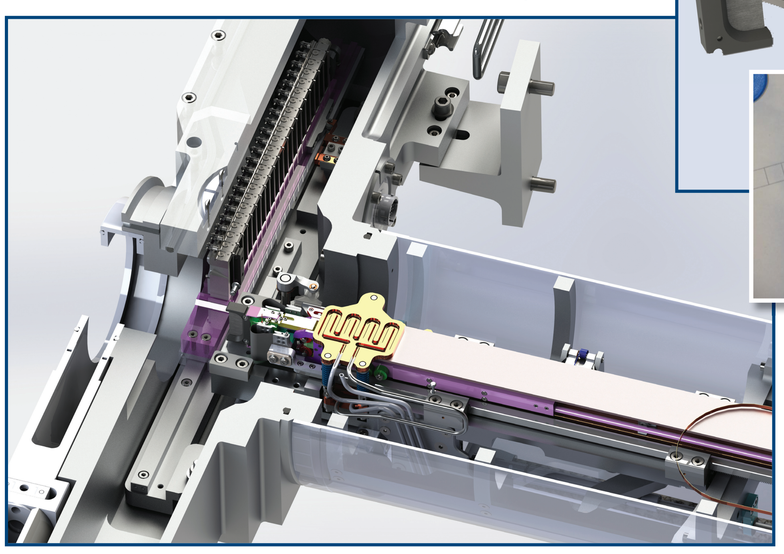
A separate hinged, side cartridge door can be manually opened (without tools) for cartridge replacement when the cyclotron is closed, is under vacuum and has an active magnetic field.

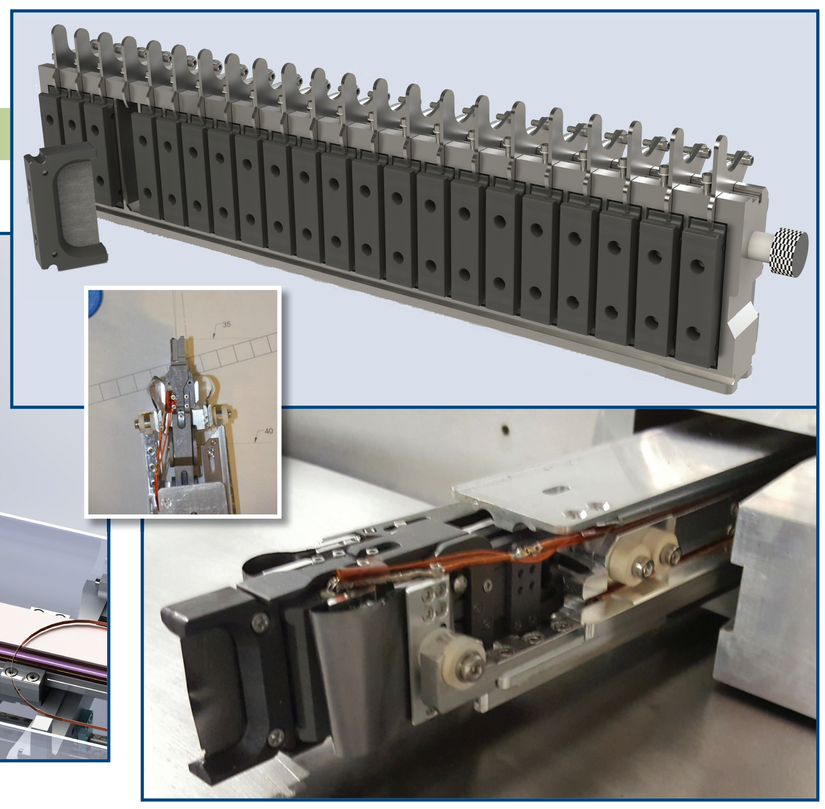
CARTRIDGE SUPPORT MECHANISM

The cartridge support mechanism is located inside the vacuum box and provides reliable positioning and movement of the cartridge. It has a retracted position and foil change positions.

The replaceable cartridge has 22 slots for graphite foil holders with a window 25 mm tall x 11 mm wide.

The cartridge and foil holders are reusable and each extractor has 2 sets to allow for easy replacement.



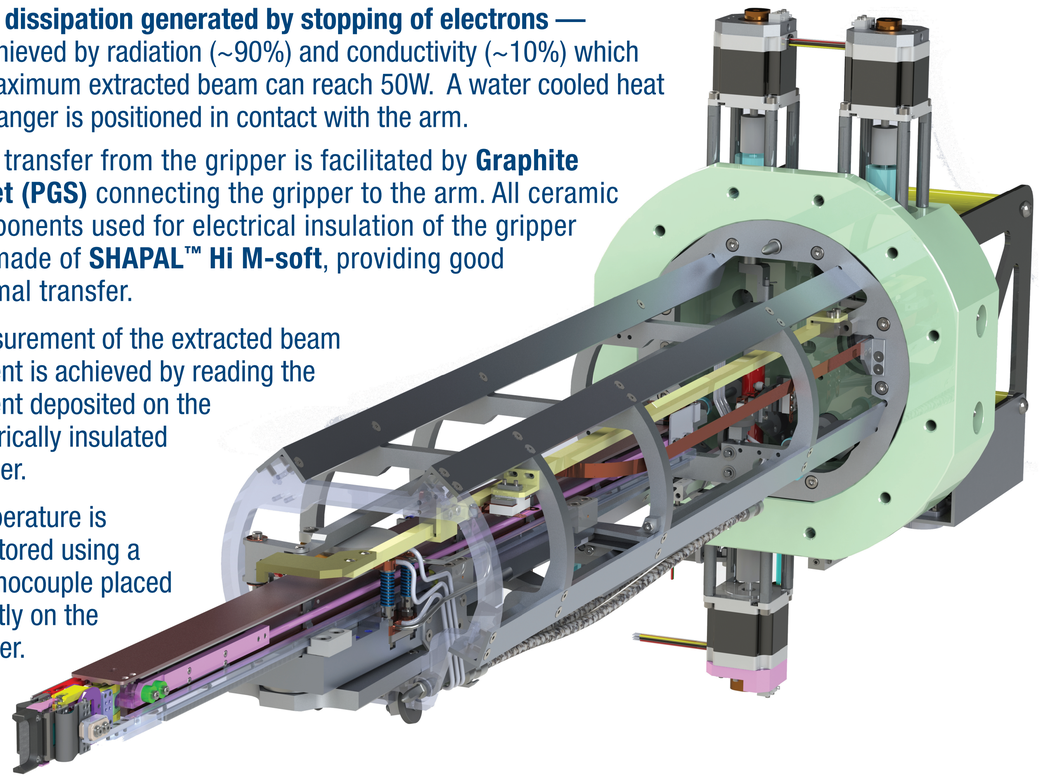


INSERTABLE MECHANISM

The insertable mechanism is the main part of the extractor and performs several functions:

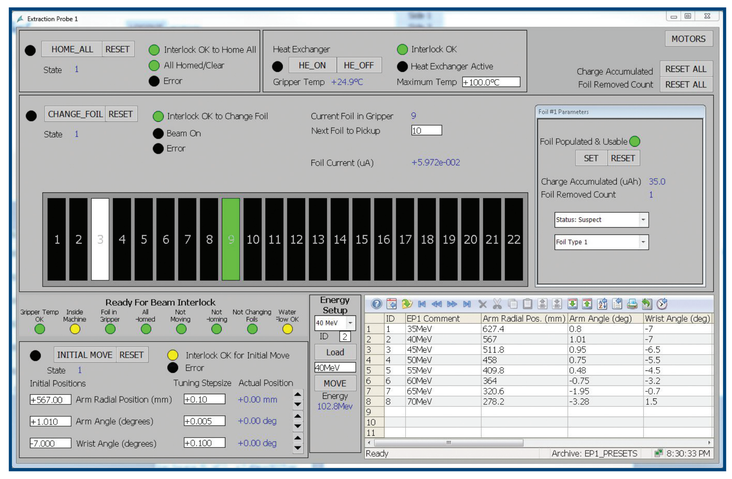
1. **Accurate positioning and orientation of the foil holder inside the cyclotron** — to ensure desired beam extraction. This is done by the arm movement in radial direction = 635 mm range, azimuthal movement of the arm base = +/– 7 degrees and gripper rotation +/– 8 degrees. All movements are using stepper motors placed outside the vacuum.
2. **Reliable foil holder gripping and secure exchange** — is achieved by a series of controlled motions of the extractor arm, gripper elements and cartridge support mechanism.
3. **Heat dissipation generated by stopping of electrons** — is achieved by radiation (~90%) and conductivity (~10%) which at maximum extracted beam can reach 50W. A water cooled heat exchanger is positioned in contact with the arm.

   Heat transfer from the gripper is facilitated by **Graphite Sheet (PGS)** connecting the gripper to the arm. All ceramic components used for electrical insulation of the gripper are made of **SHAPAL™ Hi M-soft**, providing good thermal transfer.
4. Measurement of the extracted beam current is achieved by reading the current deposited on the electrically insulated gripper.
5. Temperature is monitored using a thermocouple placed directly on the gripper.



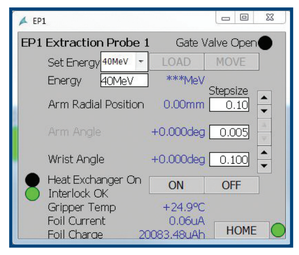
CONTROL HARDWARE & SOFTWARE

Each extractor is actuated using 6 stepper motors, controlled by Siemens S7-1200 series PLCs operating as motor indexers, with Anaheim Automation microstepping drivers supplying the power for the motors. The positioning of each axis is operated in open-loop mode, necessitating only limit switches for reindexing the home position of each axis. The acceleration profiles are optimized to ensure that the position index stays accurate during all operational conditions. Achieved positional precision allows for a very accurate beam placement on the target.



The PLC software automates the safe execution of the homing and foil change routines, as well as moving to the initial positions required for extracting beam at various energies. From these initial positions the operator can further optimize the beam extraction, accounting for foil distortion and wear, or adjusting dual extraction split ratios. The temperature of the gripper is continuously monitored to prevent overheating in case of a damaged foil or poorly tuned beam.

In conjunction with the supervisory HMI software, the following parameters are recorded and able to be reviewed at any time: Arm radial position, arm angle, and wrist angle positions, status and type of each foil, extracted current, accumulated current of each foil, and gripper temperature.



Thermal simulation that was performed during the design stage was confirmed during the first extractor usage. A significant increase in temperature is observed for a single side extraction.

Tested Foil Longevity

Components activation — no significant component activation was observed after initial extractor usage after 240h in the beam (during SAT).

Future improvements:

Several improvements are possible due to the modular design of the extractor:

- A simplified handling mechanism allowing for an increased number of foils in the Foil cartridge (up to 42 foils) and usage of single use foil holders
- A mechanism using narrow standing foils for partial extraction at lower energies combined with full extraction of the remaining beam at higher energy on the opposite extractor.

Both upgrades will use vacuum box and tube in the present installation.

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