# Upgrading Programme of the C-30 Cyclotron at Świerk and its Use for Experimental Physics

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*Abstract*

The performance of the C-30 compact, isochronous cyclotron at the Soltan Institute for Nuclear Studies (SINS) was improved during last years. The magnetic field distribution in the accelerating region of the machine was measured and field corrections were done. The stability of the RF feeding system operation was improved. The shape of a puller electrode was modified to improve the conditions of ion extraction from the source and gas pumping speed in the central region. The geometry of an internal PIG $H^-$ ion source was optimised and discharge power increased. The peak accelerated $H^-$ beam intensity at the extraction radius reached 12 $\mu$A (in pulse) and internal proton beam current – 300 $\mu$A. The $H^-$ current is still limited by stripping on residual gas molecules. An external ion source is being completed. A new computer system for monitoring of the machine operation was developed and implemented. Two experimental programmes which utilise proton beam from the cyclotron were started in 1993: 1) study of the neutron-rich nuclei from the region of symmetric fission, produced in an uranium target bombarded by 25 MeV protons,
2) study of the charged particle spectra and angular distributions from the proton induced reactions.

## 1. Introduction

The C-30 SINS cyclotron was designed for proton beams with energy up to 31.5 MeV. It is a compact, fixed magnetic field, fixed frequency, isochronous machine. External proton beams are obtained as a result of $H^-$ ions acceleration followed by electron stripping on an aluminium foil.

A detailed description of the cyclotron is given in Refs.[1–3]. The conventional type magnet was constructed for easy mounting and maintenance. The magnetic structure consists of four straight sectors with shaped surfaces, separated by four valleys, placed on each pole (Fig.1). The accelerating system consists of two 45° dees located in two opposite valleys, coupled to rectangular resonators and fed from one RF power supply. The dees are connected in the centre to get a sinphase operation. So far the cyclotron was used with a small PIG-type, internal ion source.The major features of the machine are listed in Table 1.

The cyclotron is destined for research in nuclear physics, activation analysis and for short life-time medical isotopes production. The latter requires, however, an average external beam intensity of 10 $\mu$A or more. Since $H^-$ ion beams are strongly reduced due to stripping on residual gas

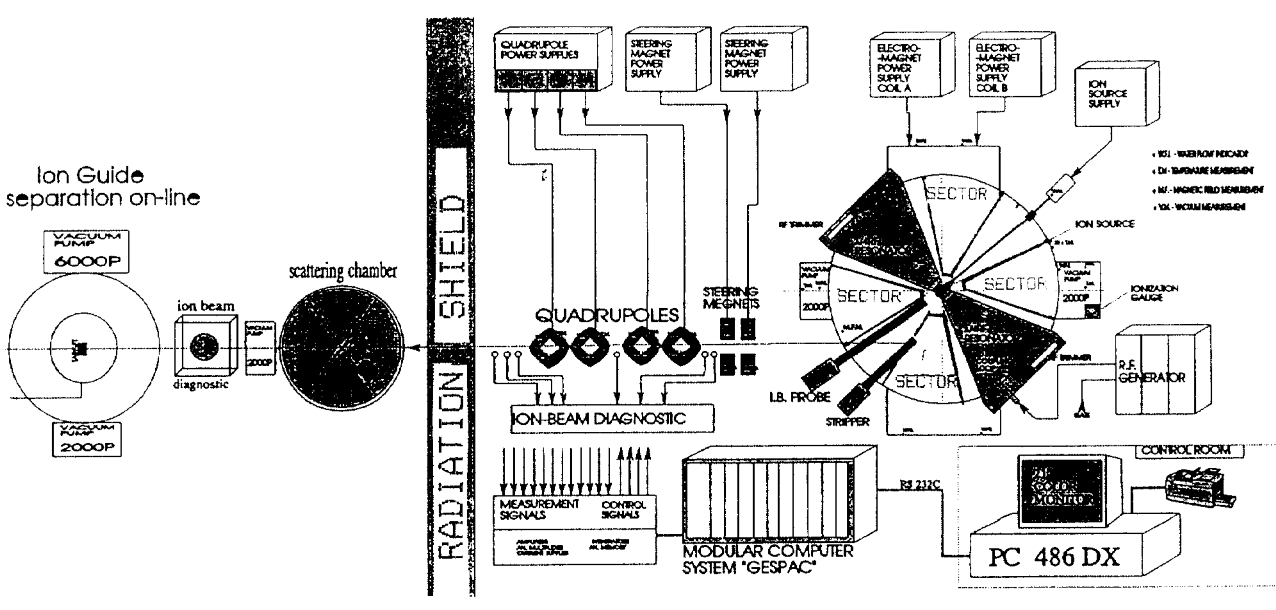


Figure 1. Block diagram of the C-30 cyclotron with power supply units and a monitoring system.

particles, an external ion source with injection system is necessary to meet these requirements. Most of the components of the injection system have been completed by now. A prototype external ion source is being manufactured at SINS.

Table 1
Major features of the C-30 cyclotron

| | |
|---|---|
| Particle accelerated | $H^-$, $H^+$ (internal proton beam) |
| Beam energy | 16 – 31.5 MeV |
| External beam average current (when using an internal ion source) | 1 $\mu$A |
| Internal proton beam average current | 10 $\mu$A |
| Energy spread at max. energy | about 1% |
| Radial and vertical beam emittance | <50 mm mrad |
| Operating frequency (fixed) | 52.83 MHz |
| Typical RF pulse length | 500 $\mu$s |
| Typical duty factor | 1/5 for $H^-$ acceleration |
| $H^-$ and $H^+$ accelerating mode | second harmonic |
| Pole diameter | 105 cm |
| Max. extraction radius | 45 cm |
| $H^-$ ion source | internal PIG, external multicusp (under construction) |
| Vacuum and pumping speed | $5\text{x}10^{-5}$ torr $1.5\text{x}10^3$ l/s |
| Method of extraction | charge exchange |
| Beam exit | single |
| Monitoring system | computer assisted industrial control systems |

## 2. Magnetic Field Corrections

The applied magnetic structure allows to reach proper magnetic field for $H^-$ ions acceleration without correcting coils. The isochronous field formation is based on proper shaping of sectors and on magnetic saturation effects occurring in them. Appropriate sector profiles can be achieved by an iterative procedure in precise machining. The previous sector profiles were not accurate enough. The machining errors exceeded 0.1 mm. The correction procedure was developed which consisted of the following steps :

– measurement of magnetic field in 8640 fixed points at the average field level corresponding to a designed $H^-$ particle gyration,

– computational simulation of particle acceleration in the measured magnetic field and RF electric fields determined by the dees geometry. The accelerated particle phase (with respect to the RF phase) indicates the average magnetic field deviation from the isochronous one at a given distance from the centre.

– estimation of an amount of iron to be added or removed at given radii in magnetic sectors, in order to minimise the deviation of average magnetic field.

The above procedure was repeated until the fluctuations of a particle phase were within the limits of $\pm$ 10°, which corresponds to local average field errors $\Delta\langle B\rangle/\langle B\rangle$ less than $5\text{x}10^{-4}$. The field corrections were done by attaching cover plates of low carbon steel to the surfaces of the sectors and valleys and by removing the surplus iron from the sectors by milling.

A first harmonic magnetic field error was revealed during the first stage of field shaping. This error induces a resonant build-up of radial oscillations, which bring about beam losses and an increase of beam energy spread. The error was corrected by a slight change in the position of the upper part of the electromagnet yoke.

## 3. Ion Production

The C-30 cyclotron is used with a small, PIG-type internal ion source, designed and made at SINS. PIG ion sources are commonly used in cyclotrons. Our goal, however, was to design a miniature source, which could be introduced transversely and installed in a narrow gap (54 mm) between the pole faces in the central region. Apart from the space restrictions the most important design limitation was a low gas pumping speed (1500 l/s).

A couple of cylindrical cathodes is heated by ionic impact and there is no need of additional filament heating, so it was possible to minimise the source dimensions to 53 mm (height) and 18 mm (width).

The position of a discharge column with respect to the ion exit slit was optimised. The shape of the puller electrode was changed to improve ion extraction conditions and pumping speed in the central region. The maximum arc current was increased from 1.5 to 4 A as a result of using an additional arc power supply. The internal source was used for generation of $H^-$ beams and internal proton beams. Its operation was tested both on a test-stand and in the cyclotron. During the test stand measurements the $H^-$ and $H^+$ yields from the source reached 1 mA and 4 mA respectively. The respective numbers for ion currents extracted in the centre of the cyclotron were 200 $\mu$A and 1.3 mA (in pulse). In order to improve vacuum conditions in the acceleration region an external compact multicusp ion source was designed and constructed at SINS. The source is to be tested soon.

## 4. Monitoring System

To ensure reliable and safe operation of the machine a system of computer monitoring was developed. It consists of an operator unit which controls flexible industrial control systems. The operator unit is based on an IBM/PC computer. The cyclotron control software was written in the $C^{++}$ programming language for Windows. The control systems, connected to cyclotron subsystems, are destined for the on-line data acquisition and processing and for execution of emergency control algorithms. The system monitors: cooling water flows, temperatures and magnetic fields in the cyclotron vacuum tank and in ion-optical elements, the ion source and vacuum system behaviour and diagnostic equipment indications (Fig.1).

## 5. Results and Conclusions

$H^-$ beam of 12 $\mu$A (in pulse) at the extraction radius, at an energy of 25 MeV has been obtained. It corresponds to a 200% growth resulting from magnetic structure modification, installation of new internal ion sources and improving the stability of the RF system operation. The $H^-$ beam reached 30 $\mu$A at an energy of 3.5 MeV (15 cm from the centre). Thus the beam transmission between the energies of 3.5 and 25 MeV was about 40% as a result of a rather high residual gas pressure. An average external $H^+$ beam current in a target chamber was 1 $\mu$A. So far this intensity was satisfactory from the point of view of experimental programmes performed at SINS during last two years. Further improvement of the beam intensity is only possible through installation of an external ion source together with an injection system.

## 6. Research Projects

### *6.1. Ion guide isotope separation on-line – IGISOL*

The combination of a cyclotron with an ISOLDE-type magnetic separator constitutes an unique and very efficient way for studying very neutron-rich nuclei far from the stability line [4,5]. Providing the proton energy is about 30 MeV and the beam intensity of $\geq$ 1 $\mu$A, it is possible to study the products of proton induced fission. The fission products have already been investigated in devices close to reactors, basing on neutron induced fission.

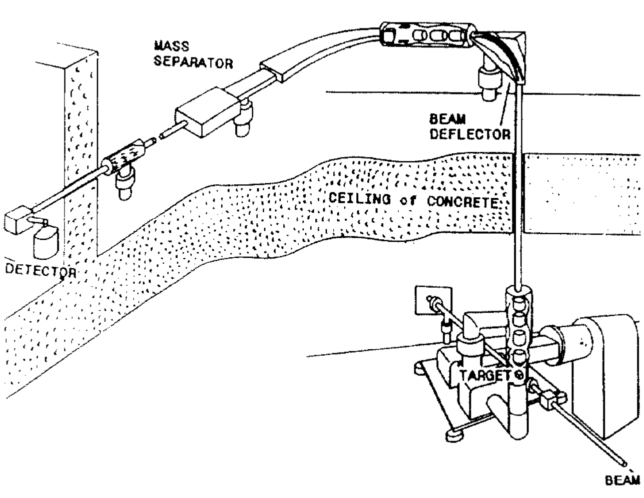


Figure 2. Overall view of the IGISOL facility at Świerk

The mass distribution pattern is different in both cases and for proton induced fission enhances the less known region of symmetric fission. In the experiment performed at SINS, a 25 MeV proton beam bombarded an uranium target in the reaction chamber (Fig.2). The reaction products were dragged by a combination of helium jet and electric field of electrostatic lenses, introduced to a mass separator and studied spectroscopically. Gamma-rays spectra for the chain of isobars with mass A = 113 were measured. Some of the measured gamma-lines belong to the neutron-rich isotope ${}^{113}_{44}Ru_{69}$.

Overall view of the IGISOL facility at Świerk is shown in Fig. 2.

### *6.2. Investigation of the $^{27}Al(p,\alpha)^{24}Mn$ reaction*

The $\alpha$ spectra from the $^{27}$Al(p,$\alpha$)$^{24}$Mn reaction are measured using a proton beam from the C-30 cyclotron. The $\alpha$ transition to the 9.5 MeV, T = 1 state in residual nucleus $^{24}$Mn is studied for the proton energy range 20–26 MeV, in order to obtain the excitation function of this state. The excitation by the $\alpha$ emission of the giant dipole resonance, excited as a doorway state in $^{28}$Si composite nucleus, is looked for.


## 7. Acknowledgments

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## 8. References


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