2017 International Nuclear Atlantic Conference - INAC 2017
Belo Horizonte, MG, Brazil, October 22-27, 2017
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6

A SIMPLE AND POWERFUL XY-TYPE CURRENT MONITOR FOR 30 MeV IPEN/CNEN-SP CYCLOTRON

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ABSTRACT

A water-cooled XY-type current monitor was designed and built in the Cyclotrons Laboratory of the Nuclear and Energy Research Institute (IPEN). It is a very simple design and easily adaptable to the cyclotron beam lines. Tests were done demonstrating to be an instrument of great assistance in proton beam position along beam transport line and target port. Nowadays the XY-type current monitor has been widely used in ^{18}F-FDG routine productions, employing irradiation system which were originally designed for productions on 18 MeV cyclotron accelerator only, however, applying the XY-type current monitor the target port may be exchanged between the 30 MeV and 18 MeV cyclotrons and the observed results are in perfect agreement with expected.

INTRODUCTION

On August 28, 1998 a new cyclotron, manufactured in Belgium by "*Ion Beam Applications*" company, starts operations in the Nuclear and Energy Research Institute laboratories located in São Paulo, Brazil. This machine accelerates protons with kinetic energy between 15 and 30 MeV and beam current up to 300 μA [1]. It has two external beam transport lines on opposite sides allowing the targets irradiations in two confined rooms as shown in figure 1.

Since installation and commencement of operations Cyclone 30 has been used for solid, liquid and gaseous targets irradiations in ^{18}F-FDG, ^{67}Ga, ^{201}Tl and ^{123}I routine productions.
In liquid and gaseous targets irradiation room, at the end of the beam transport line, there is a switch magnet that allows irradiations in five different positions [2].

Due to the great length of the beam transport lines (6 m long), there is a need for beam control and spatial positioning by means of devices inserted between the cyclotron and the target. These devices are quadrupole magnetic lenses (doublets or triplets) that are used for beam focusing and vertical/horizontal magnetic positioners (steerings) for beam centering on the target. In general, the target ports have a circular-shaped beam collimator whose diameter does not exceed 10 mm, so it is very important that the proton beam passes through the collimator and reaches the center of the target without losses.

For this reason an XY-Type Current Monitor was designed and constructed which allows the cyclotron operators to adjust the beam spatial position before passing through the target collimator in order to reach the center of the target with maximum efficiency.

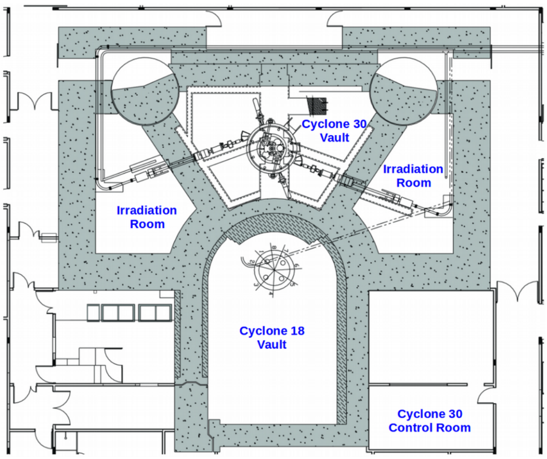


Figure 1: Cyclone 30 cave and irradiation rooms

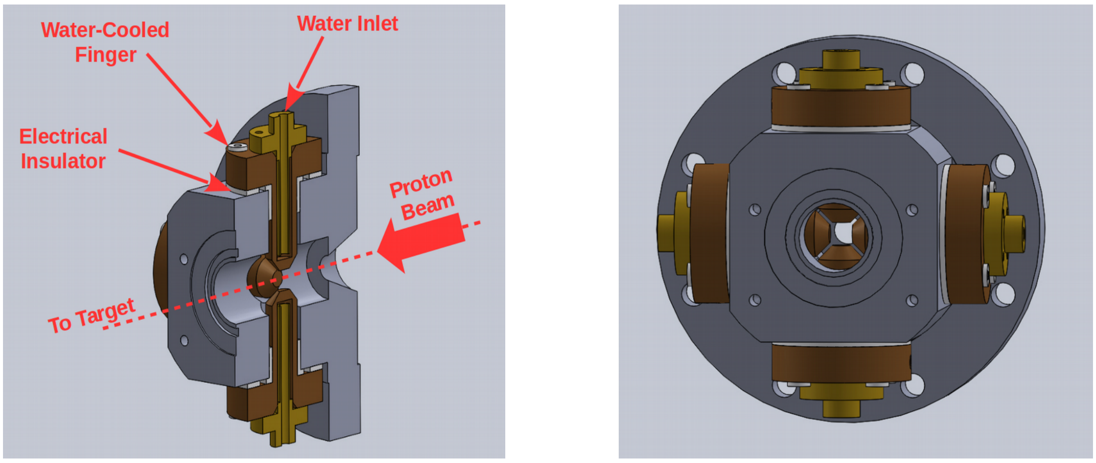
In 2008 another cyclotron is installed on the premises of the Nuclear and Energy Research Institute, a Cyclone 18/9 also built by "*Ion Beam Applications*" from Belgium. This new cyclotron can accelerate protons to fixed energy of 18 MeV with beam current up to 100 μA, it has eight beam output ports that can irradiate up two of them simultaneously [3]. In each of these outputs there are beam gates that isolates the cyclotron vacuum chamber from the target port. These targets port were developed particularly for use only in Cyclone 18/9 cyclotrons, but with the design and construction of the XY-Type Current Monitor these targets can be irradiated in both Cyclone 30 and Cyclone 18/9, which has provided tremendous benefits for the Institute, since there will always be ^{18}F-FDG productions even if one of the two cyclotrons are stopped for maintenance.

1. THE XY-TYPE CURRENT MONITOR

There are several techniques for beam profile monitoring of electrically charged particles that have been used with great success in several research centers and laboratories producing cyclotron radioisotopes [4-8].

The beam current monitor presented in this work is very simple in design. It is composed by water-cooled "four fingers" mounted in a single block as shown in figure 2. The material used is 6063 or 6061 aluminum and the electrical insulator rings are made of PEEK (*PoliEter-Etil-Ketone*) [9].

The body of current monitor is mounted on one of the five outputs of the switch magnet in the liquid and gaseous irradiation room, in a DN100 standard high vacuum valve, and on the opposite side an aluminum plate is mounted where the Cyclone 18/9 beam gate are fixed, as can be seen in figure 3, which will enable the Cyclone 18/9 target ports to be also mounted and irradiated in the same way on Cyclone 30.



(a) **(b)**

Figure 2: (a) Cut-out of the current monitor aluminum body; (b) Fully assembled XY-Type Current Monitor

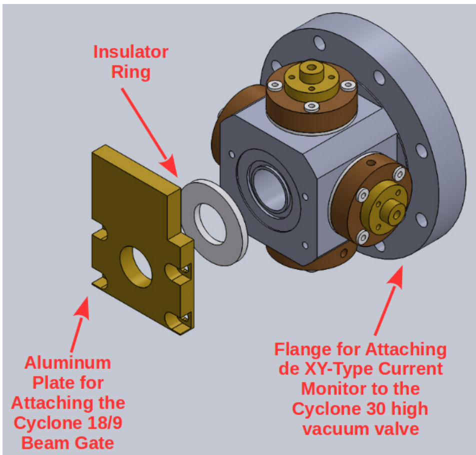


Figure 3: Aluminum plate for attaching the Cyclone 18/9 beam gate and flange for attaching Cyclone 30 high vacuum valve.

2. ELECTRICAL INSTRUMENTATION

The electronic instrumentation used to monitor the spatial beam profile is composed of a data acquisition unit (hardware) that is directly connected to the XY-Type Current Monitor and a data processing unit (software) that converts the analog signals into digital ones. The nominal values of currents on each finger are shown on the computer screen of the control room so that the cyclotron operator can make the necessary spatial positioning of the beam on the target.

2.1. Hardware

The beam monitoring technique used in this work is based on the interception of the proton beam by means of cooled aluminum collectors (fingers or sectors) and the measurement of the induced electric current (by secondary electrons) produced in the finger or sector [10].

The electrical signals from each sector are conducted by means of 50 Ω coaxial cables to the data acquisition unit located in the cyclotron control room, 50 meters apart.

In the data acquisition unit, current-to-voltage converters convert the induced electric currents from the sectors into voltages (0-5 V). These signals are sent to the analog inputs of the PIC micro-controllers (Microchip) [11,12] that convert the signals into 10-bit digital data. These, in turn, are sent via serial RS-232-C interface [13] to a personal computer where they are recorded and displayed in real time on the computer screen so that the cyclotron operator can monitor and make the necessary corrections.

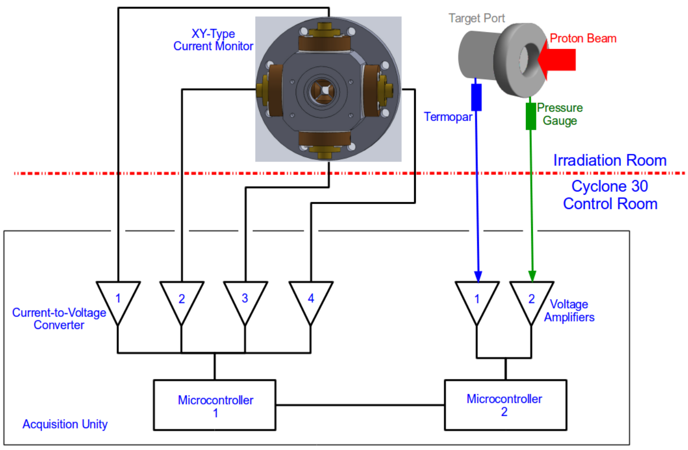


Figure 4: Electronic instrumentation used in XY-Type Current Monitor

2.2 Software

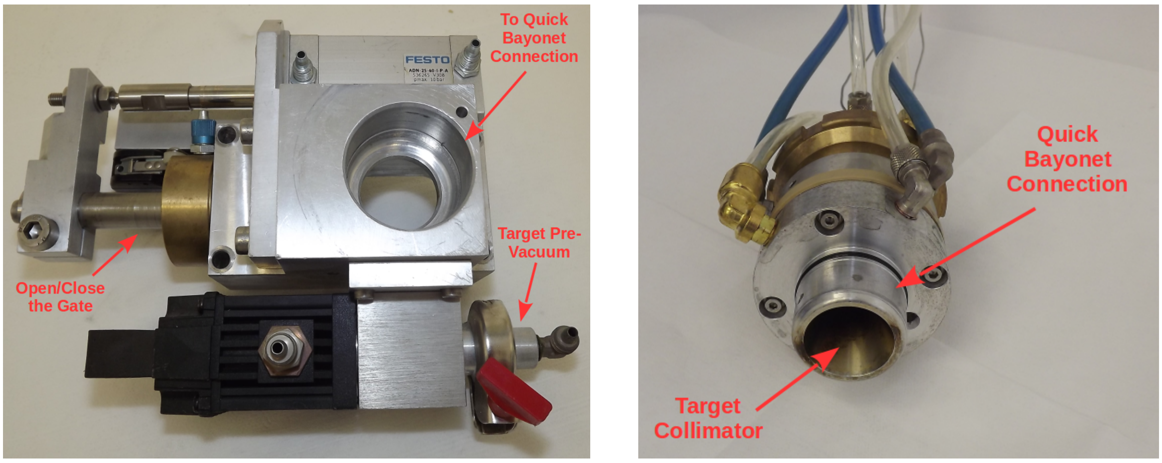
All operations performed by the micro-controllers (acquisition, analogue-digital conversion, serial communication, etc.) are established via *ASSEMBLER* programmed routines and recorded in their *EEPROM* data memories.

An application developed in *MS Visual Basic 6.0*® allows the cyclotron operator to monitor in real time on the personal computer screen the behavior of the spatial beam profile during the entire irradiation time, namely, the value of the beam current in each one of the sectors by reading the data from the respective micro-controller buffers with a data refresh interval of 0.5 sec.

The program also allows to store the values obtained in the data acquisition in a file (.mdb - *MS Access*®) for future analysis. This data is recorded every 2 seconds. A records routine allows data to also be displayed in the form of a chart versus time.

3. IRRADIATION TESTS

For the XY-Type Current Monitor tests, a medium volume (3000 μl) ^{18}O-enriched water target port was used and several irradiations were made modifying the beam spatial profile so that it was possible to verify the current readings in each water-cooled fingers. Figure 4 shows the Cyclone 18/9 beam gate used in these assemblies and the ^{18}O-enriched water target port used in the current monitor tests and figure 5 shows the XY-Type Current Monitor and Cyclone 18/9 standard beam gate assembly mounted to the Cyclone 30 switch magnet output port in the liquid and gaseous irradiation room.



(a) (b)

Figure 4: (a) Cyclone 18/9 standard beam gate; (b) Cyclone 18/9 ^{18}O-enriched water target port used in the XY-Type Current Monitor tests.

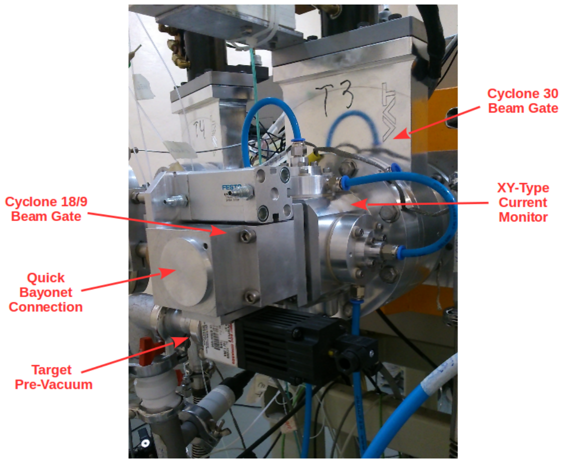


Figure 5: XY-Type Current Monitor assembled on Cyclone 30 beam gate

4. RESULTS

During the XY-Type Current Monitor irradiations tests, the proton beam was purposely moved horizontally (x-direction) both to the left and to the right, and in the same way in the vertical direction (y-direction) up and down. Plots of the current readings on the four water-cooled fingers were made in real time to verify the equipment operation as shown in Figures 6, 7 and 8. These figures show the application main screen during a typical irradiation for ^{18}F-FDG production. In these screens four main fields can be highlighted: a front view of the current monitor (upper left corner) where the four "cooled fingers" with their respective beam current values can be seen; chart of beam currents as a function of time (top right) and target and collimator beam current chart (bottom right); target port pressure and water cooling temperature values (in the middle left).

Figures 6 and 7 show a slightly scattered beam profile in the X-direction and faced down in the Y-direction. Figure 8 shows a focused beam in the Y-direction and widely scattered in the X-direction.

Other relevant parameters that are also monitored by the data acquisition system are the current in the beam collimator, the total current integrated into the target, the temperature of the water cooling and the pressure inside the target port.

The values of these parameters are shown on the current monitor main screen and also assist the cyclotron operator during irradiation. If the beam profile is good, but the temperature and/or pressure is too high, this may cause damage to the system and may lead to the breakage of the target port windows. Before this occurs the cyclotron operator must intercept the proton beam to prevent the leakage of radioactive material or the cyclotron vacuum loss.

The tests performed with the current monitor as well as the data acquisition and processing units were done during routine ^{18}F-FDG productions. The behavior of the components was monitored throughout the production time and the observed results are within the expected.

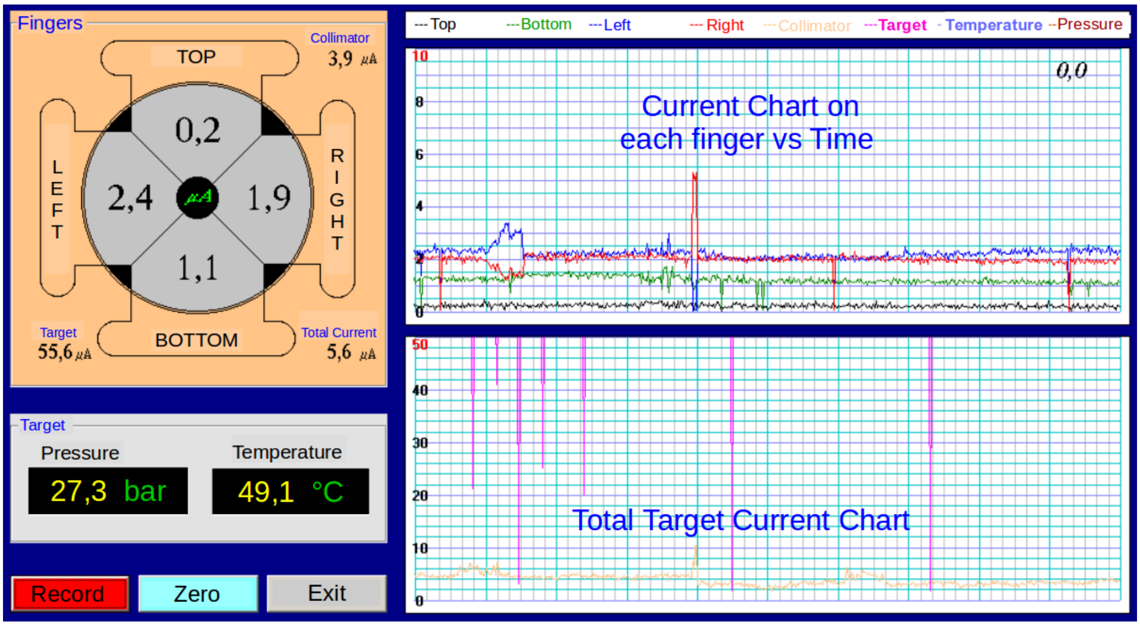


Figure 6: XY-type Current Monitor screen during typical ^{18}F-FDG production.

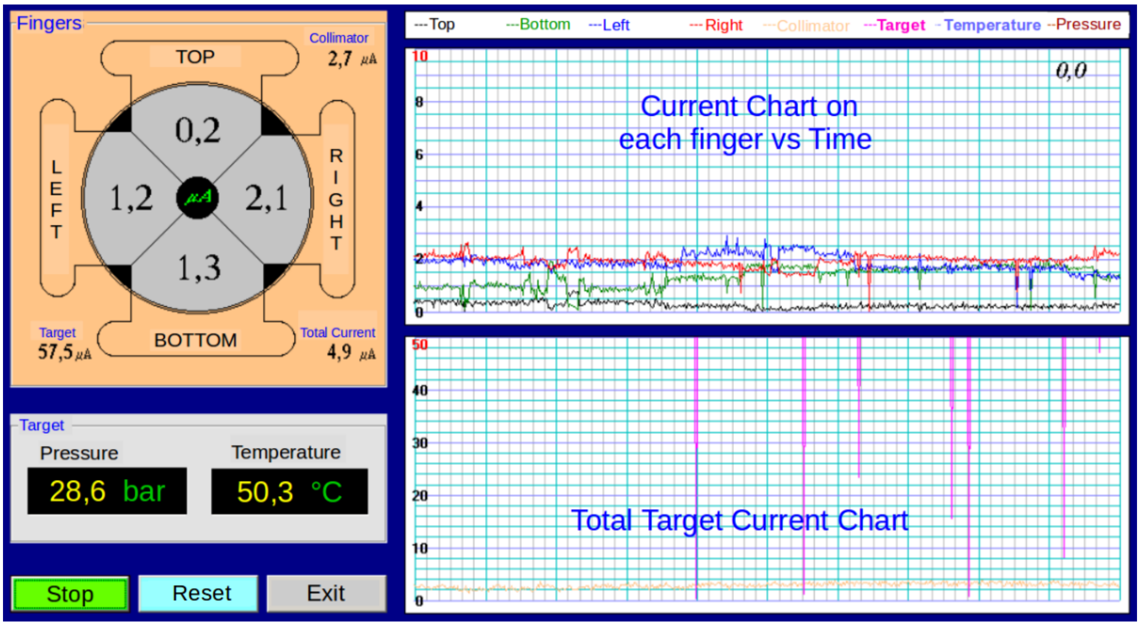


Figure 7: XY-type Current Monitor screen during typical ^{18}F-FDG production.

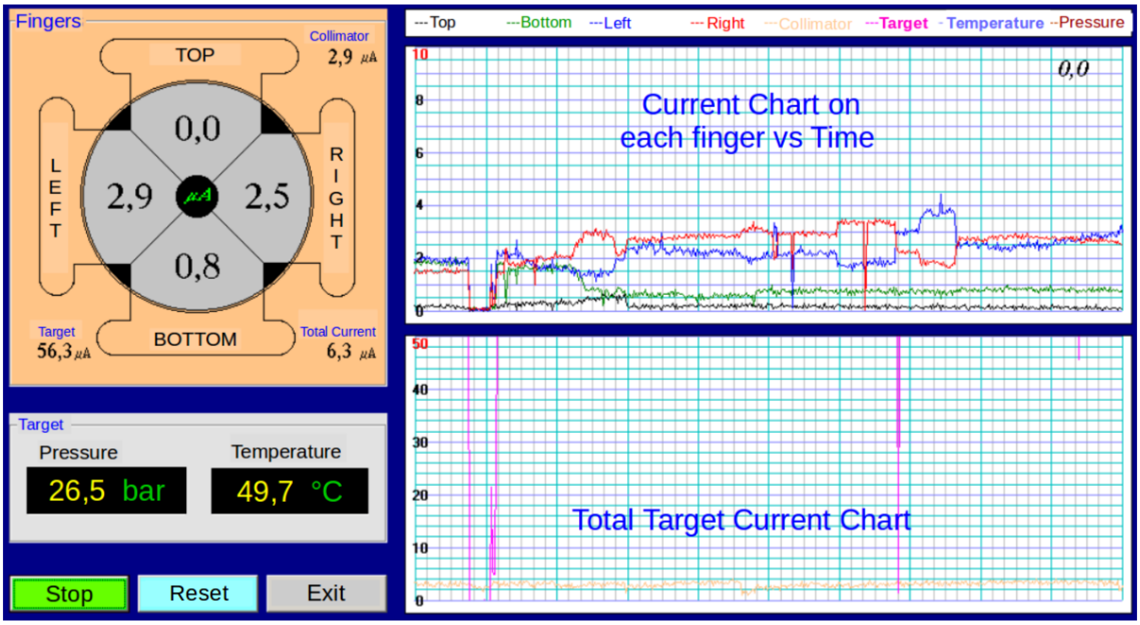


Figure 8: XY-type Current Monitor screen during typical ^{18}F-FDG production.

5. CONCLUSIONS

The results obtained with the current monitor tests were satisfactory. The real-time visualization of the beam spatial profile allowed the cyclotron operators a better control on the positioning of the beam in the best region of the targets irradiation. Beam current measurements on the collimator and target allow the efficiency (target/collimator ratio) to be optimized in a shorter time.

Compared to commercial beam monitoring systems, the XY-type current monitor designed and built in the IPEN laboratories is cheaper and its effectiveness has been demonstrated in a way that other identical devices have been constructed and will be assembled on the others Cyclone 30 beam lines.

In the future, will be designed and constructed a beam spatial monitoring system composed of a double set of monitors similar to the one shown in this paper, mounted axially and spaced 50 cm apart. The objective is to improve the beam profile in gas target irradiations, as these are longer than those used in ^{18}F-FDG productions.

ACKNOWLEDGMENTS

The research team involved in this project thanks the Radiopharmacy Center of the Nuclear and Energy Research Institute for the financial and material support made available, without which this work would not have been possible.

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