A 'SHORT PORT' BEAMLINE FOR MOUNTING CUSTOM TARGETS TO A GE PETtrace™ CYCLOTRON

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Abstract

A very short (150 mm long) beamline known as the "Short Port" beamline has been developed. It enables users to mount custom high performance targets on their PETtrace™ Cyclotrons. The "Short Port" beamline comes complete with a gate valve, 4-jaw and water-cooled graphite collimator with beam current readbacks, a thermocouple port, and, in the baseline version, a flange for mounting the Thermosyphon Target developed by Bruce Technologies for production of Fluorine-18 [1]. This paper describes the design, development and testing of the "Short Port" beamline.

INTRODUCTION

The concept for the "Short Port" beamline follows from the development of a Fluorine-18 water target [1] capable of irradiation by more than 3.2 kilowatts of beam power. This corresponds to hundreds of micro-amperes of proton beam at PET energies of 10 MeV to 19 MeV. With such high beam currents required to fully utilize a high production target, it is important to ensure that the beam is well-centred and properly focused on target. This can be achieved with appropriate diagnostic instrumentation and feedback control to adjust cyclotron or beamline parameters. If not, a high power beam could cause catastrophic equipment failure if mis-centred, or, at the very least, sub-optimal radioisotope production.

There are two approaches. First, a compact beamline could be utilized as described in [2] with focusing, steering and diagnostic capabilities, or, second, a "Short Port" design could be utilized for self-shielded cyclotrons as described in this paper. The "Short Port" provides more comprehensive diagnostic readback capabilities than are provided by most PET cyclotron manufacturers between the stripper and the target, and it also provides a means for custom targets to be mounted to commercial cyclotron exit ports.

This paper describes the design, development and testing of the "Short Port" beamline in which the design and commissioning approaches described in [3,4,5] are utilized.

SHORT PORT BEAMLINE DESIGN

Specifications

Although most commercially available PET cyclotrons do not have the beam power output to fully utilize the production capabilities of the Thermosyphon target, the developer, Bruce Technologies, is interested to make its target technology available on a commercial basis. This offers interesting possibilities, since all of the available beampower on most commercial PET cyclotrons could be utilized for production. In order to do this a convenient and well instrumented connection between the target and the cyclotron was deemed necessary. For the first test case of a "Short Port" beamline used to connect a Thermosyphon target to a PETtrace™ cyclotron the following specifications were to be met:

- fasten and seal to cyclotron exit port.
- gate valve for vacuum isolation.
- water-cooled 4 sector collimators with four isolated beam current readbacks.
- nominal 12 mm collimator aperture.
- thermocouple port.
- leak detection and pump port.
- fasten and seal to Thermosyphon target.
- minimize space occupied.
- X & Y adjustment capabilities.
- interference with neighbouring targets, valves, assemblies, services, and shielding not permitted.
- utilize low activation, low neutron production, and radiation resistant materials.

With regards to low activation and low neutron production materials, there are three categories. First for vacuum box devices which may be struck by stripped neutral beam (in H^- machines) such as a main cyclotron vacuum tank or the "Short Port" vacuum components, Thorson [6] shows that aluminum is the best choice over stainless steel. Second for the case of beam intercepting diagnostic devices, materials with a low neutron production rate are sought. Thorson [6] shows that for incident protons in the 0 – 32 MeV range, carbon yields the fewest neutrons by a factor of 5.5 lower than aluminum, a factor of 10.5 lower than iron, and a factor of 14.6 lower than copper. Third for achieving low residual activation after bombardment by protons, Thorson [6] shows that carbon is the best choice over copper. Therefore the "Short Port" beamline utilizes an aluminum vacuum chamber, and graphite collimators.

Beamline Layout

An exploded view of the "Short Port" beamline is shown in Figure 1. The primary pieces of the beamline are numbered, and are referenced in the following text.

The “Short Port” beamline mounts directly to any of the exit ports of the cyclotron (1) by way of an o-ring seal between the upstream flange of a custom VAT™ gate valve (2) used for this purpose. The valve utilizes separate in/out airlines, and built-in limit switches that function in a magnetic field environment.

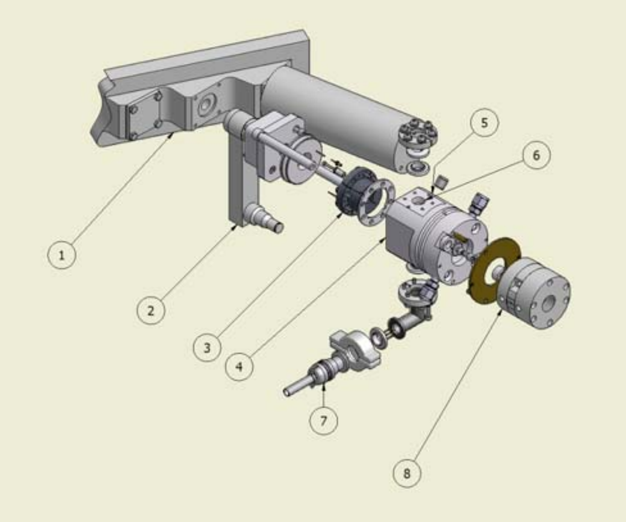

Figure 1: Exploded View of the “Short Port” Beamline.

The “Short Port” beamline is comprised of a four-jaw water-cooled (3/8 inch tube fittings) graphite collimator (3) housed in a compact aluminium vacuum chamber (4) that incorporates, a threaded access port (5) for a thermocouple (¼ NPT), and an ISO16 roughing port (6). The 4 wire quick-connect electrical connector (7) is provided for cabling the collimator readback currents back to the control system. The vacuum chamber is hardcoat anodized for electrical isolation. The chamber is fastened to the cyclotron vacuum tank by four threaded fasteners that compress the VAT™ valve between the cyclotron vacuum chamber and the “Short Port” beamline vacuum chamber. A target assembly (8) or other beamline hardware may be mounted to the downstream face of the vacuum chamber. In this case a proprietary mounting scheme suitable for Bruce Technologies’ targets has been utilized. Custom or standard flange interfaces of any sort may be utilized for the downstream flange solution.

The “Short Port” beamline is supplied with several sets of graphite four jaw collimators with a range of apertures, so the appropriate collimated beam size can be chosen for the application. A 12 mm aperture has been appropriate for use with the PETtrace™ system. The Short Port beamline permits adjustment of the centering of the device to accommodate off-centre beams, if necessary.

Commissioning & Testing

A “Short Port” beamline was built, and installed on a PETtrace™ cyclotron as shown in Figure 2. The device uses the standard air and water service lines available for this purpose. Independent beam current readbacks were monitored and a 12 mm collimator was utilized for the beam runs.

Initially the graphite collimators require to be baked out by means of exposure to a few micro-amperes of beam current for an hour or so. This stabilizes the vacuum and tests ran smoothly thereafter. For optimal sizing of Bruce Technologies’ Thermosyphon target it was important to determine an appropriate aperture size for the collimators and the target. Several sets of collimators were provided, so that an optimal set could be chosen.

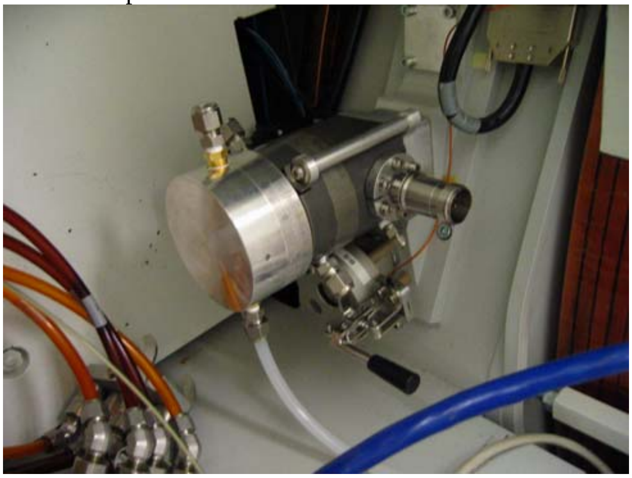

Figure 2: The installed “Short Port” beamline with diagnostic target attached.

Initial experiments were undertaken with a ~3 micro-ampere proton beam extracted from the cyclotron, transported through the “Short Port” beamline, and deposited on a quartz scintillator to yield a visual determination of the beam spot intensity distribution, refer to Figure 3. The beam was found to be well centred with no apparent hot spots. Although, a detailed analysis of the beam spot intensity distribution was not possible due to saturation of the scintillator image. The well-defined circular beam spot image confirmed the beam is being collimated through the 12 mm diameter of the 4 jaw graphite collimator.

Figure 3: Beam spot image of a micro-ampere level proton beam extracted from a PETtrace™ Cyclotron, transported through the “Short Port” beamline, and deposited on a quartz scintillator.

Next, low current measurements (~6 micro-amperes) were undertaken using the cyclotron hardware, the "Short Port" hardware, and the Target hardware. The beam was swept across the the collimators and target by adjusting the stripper foil position as shown in Figure 4. The figure establishes the beamspill readback capabilities of both the PETtrace™ collimators provided inside the cyclotron tank, and the "Short Port" 4-Jaw collimators located outside the cyclotron tank and immediately upstream of the target. Beam transmission to target was 84%. This is reasonable. A beam too tightly focused risks rupturing a target window, and a defocused beam offers the significant advantage of more uniform vapour generation in a boiling target (no "drilling" through target medium).

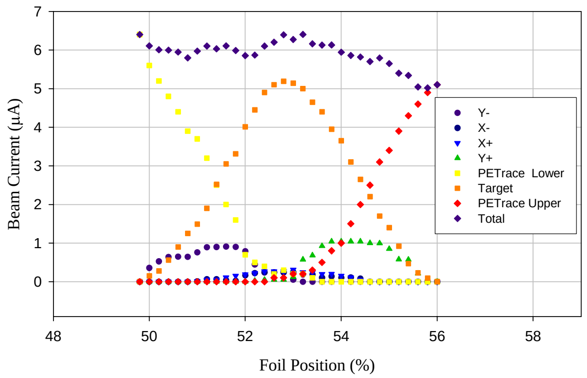

Figure 4: A beam sweep across the target by adjusting the stripper foil position. Y-, Y+, X-, X+ show beam on the "Short Port" Collimator, and Internal Y-, Internal Y+ show beam on the collimators inside the cyclotron.

The final test to be undertaken was the high current beam test (refer to Figure 5). The beam transmission to target was 80%, which is reasonable, but may be adjusted through re-sizing of collimator apertures as necessary.

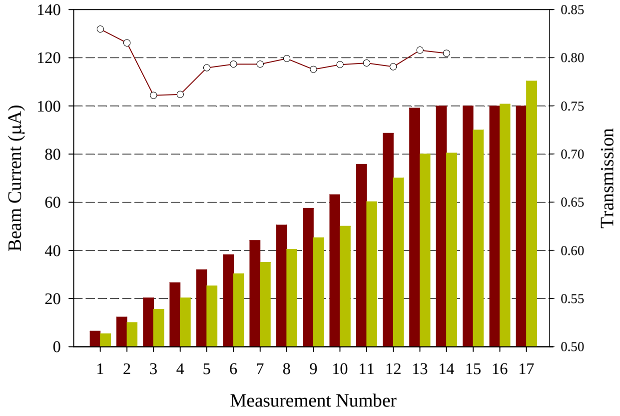

Figure 5: The stripper Foil Current and Target Current for the case of a 12 mm diameter "Short Port" collimator aperture.

The PETtrace™ command control system does not report beam stripper Foil Current higher than 100 µA, although it is clear this has been achieved. A total beam current of over 110 µA (1.87 kW beam power) was achieved on target with excess capacity still available in the PETtrace™ system (i.e. ion source power, and RF power not fully utilized). This bodes well for the Bruce Technologies' targets such as the Thermosyphon, which can accommodate beam powers of 3.2 kW and more.

ACKNOWLEDGEMENTS

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CONCLUSIONS

A description of the "Short Port" beamline design and development has been given. This device increases the level of beam diagnostics which can be readback to a control system for beam tuning purposes in a PETtrace™ cyclotron. It also provides a means for mounting custom targets to such a cyclotron. The device performed well in practice, and met its functionality requirements. This device may have wider applicability to other PET cyclotrons.

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