Evaluation of hydrogen gas flow system in DECY - 13 cyclotron

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Abstract. The Center for Accelerator Science and Technology (CAST – BATAN) is developing a cyclotron that eventually will be used for radioisotope production. The cyclotron accelerates charged particles \((H^-)\) generated by ion source through circular trajectories up to the desired energy and form proton beams through an extraction system. In the early operational stage, the beam current strongly influenced by the flow speed of hydrogen gas in the head of an ion source, therefore the gas flow performance needs to be characterized. Evaluation have been undertaken which cover component identification, data collection and analysis of the obtained data. The operational data of the opening gas valve is represented by the voltage and flow rate. This evaluation results can be used as a basis or guidance for further construction of the ion source instrumentation control system.

1. Introduction
PET (Positron Emission Tomography) has been effectively used to detect cancer with accurate imaging results. This technology is becoming the most useful technique for diagnostic imaging. For some developing countries, it is hard to make a policy in the construction of the PET/CT facility. They should consider about the siting cost, annual cost, staff cost, etc. which is relatively high. In addition, the cost for human or professionals resource is also high[1]

Center for Accelerator Science and Technology (CAST)-BATAN which is a government institution that has focus on accelerator research is conducting a research and development of cyclotron and PET/CT facility in Indonesia. Commissioning and optimization of several components are still carried out until now. One of the main components is ion source which has the function to generate particle beams. The operation parameters of the ion source significantly affect the initial beam quality before being accelerated. The optimized parameters are either fixed or variable parameters. Maximum beam current can be obtained if the ion extraction process from the ion source and the acceleration process are perfect. In this case, we are eager to minimized the beam loss that will give advantages in operating cost and radiation exposure[2]

We began the construction of an ion source with the installation of gas supply equipment. In the next stage, some parameters were observed such as cathode and puller voltages, hydrogen gas flow, and magnetic field strength[3]. The test results show the proportionality between the percentage valve opening at proportionating selection valve (PSV) and flow rate which is indicated in Mass Flow Meter (MFM) even though there is no linearity between them[4]. After the ion source testing device was completed in 2015, the ion source experimental equipment was successfully made and tested. The result shows the gas flow rate is in range of \(5 - 10 \text{ sccm}\)[5]. This flow rate is comparable with SC (superconducting) cyclotron 8.5 MeV, the gas handling system controls the flow rate of \(H_2\) into the
source in a range of 0 to 10 sccm [6]. For KIRAMS 13 cyclotron, the measured maximum beam current at the target was 48.3 micro amperes under 2 ampere arc current and 7.5 sccm hydrogen gas flow rate [7]. Similar condition also apply to the DECY 13 cyclotron, for commissioning preparation or operation a vacuum condition around $1 - 2 \times 10^6$ torr is required so that when the 5 sccm hydrogen gas flow enters the vacuum is around $7 - 8 \times 10^6$ torr [8]. Therefore the flow rate of hydrogen gas is set in the range of 5 – 10 sccm in order to tolerate the vacuum stability.

In 2018, installation process of ion source at cyclotron DECY 13 had been finished. This equipment had been installed at building no. 05 CAST – BATAN Yogyakarta. Based on the experiment and evaluation in 2015, some components were replaced and added, including the addition of a gas regulator with a double barometer and PSV replacement with a gas regulating valve EVR 116. The installations of these components were expected to obtain a gas flow that is more stable and easier to control. In addition, the use of EVR 116 made the initial opening gas flow more stable, and beam quality during cyclotron operation maintainable [7][9]. Therefore, various tests and evaluation must be conducted in order to assess the performance of the system. Data testing was processed and analyzed in order to obtain the characteristic curve that reflect the control valve performance [10].

2. Experimental Method

2.1. Identification of DECY 13 hydrogen gas flow system

Hydrogen gas flow system devices on a DECY 13 cyclotron consist of five components as shown in Figure 1 and Table 1. A gas tube with a volume of 1 m$^3$ supplies hydrogen gas to the head of the ion source. Next, the gas passes through a regulator equipped with a barometer to estimate the initial gas pressure before passing the control valve. Before the control valve, a manual valve was installed as a safety if the control valve did not function properly.

*Figure 1. Gas flow system for DECY 13 cyclotron.*

The type of control valve used in this system is EVR 116 with an operating voltage from 0 – 10 V DC and wide range operating characteristic that is from $10^{-6}$ mbar l/s to 1250 mbar l/s. The unit used in the measurement is sccm or cm/min which is equivalent to 0.016 mbar l/s. The control valve can be controlled manually using a potentiometer or up/down switches, or operated automatically using a control module. A measurement tool uses a mass flow meter (MFM) AALBORG GFM 17 which is measures gas flow rate before the gas is delivered to the ion source head. The output characteristics are 0 – 5 V DC with the minimum impedance load of 1000 ohm, and the required power supply is 12 V DC. By knowing the gas flow rate, the performance of the system can be known.
Table 1. Components of the hydrogen gas flow system of DECY 13 cyclotron.

| No | Component | No | Component                        |
|----|-----------|----|----------------------------------|
| 1  | Hydrogen gas tube 1 m$^3$ | 4  | EVR 116, Gas regulating valve, motorized |
| 2  | Gas regulator and gauge       | 5  | Mass Flow Meter (MFM) AALBORG GFM17 |
| 3  | Manual Valve                   |    |                                  |

2.2. Equipment working principle
The block diagram of a hydrogen gas flow system is presented in Figure 2. Gas flows from the tube through the regulator, manual valve, EVR 16, MFM, and ion source head. The gas flow rate is read by MFM before entering the ion source head which is located in the cyclotron vacuum chamber. The process of adjusting the valve voltage and the acquisition of gas flow rates from MFM are arranged in the instrumentation and control system. This system includes a computer, Analog to Digital Converter (ADC) module, and Digital to Analog Converter (DAC) module which is a combination of PLC and National Instrument. On the other hand, MFM also has an LCD as a flow rate display.

![Flow diagram of the hydrogen gas flow from the tube to ion source head in the cyclotron chamber.](image-url)
Some parameters were recorded during operation e.g., the initial pressure displayed on the barometer which is mounted on the regulator. They were recorded to determine the stability of the initial gas flow conditions. After that, the valve controller voltage was adjusted step by step while observing the change in the flow rate of the hydrogen gas that is read on the MFM. Initial pressure, gas flow rate on the MFM display, and vacuum conditions data were recorded manually. While the valve voltage and the output voltages of the MFM were recorded automatically on the computer.

The recorded data is then processed and analysed to determine the system performance. One of the analysis aims is to understand the characteristic of the installed control valve. Basically, a control valve has two characteristics which are inherent and installed characteristics. The installed characteristic is the relationship between valve position and flow in the specific system being considered, taking into account any changes in the pressure differential available to the control valve due to the flow squared relationship between flow and piping pressure losses and or the behaviour of a centrifugal pump’s head curve.

3. Discussion

The first data to be recorded was initial pressure that read from the barometer on the regulator. The gas pressure came out from the tube was 500 – 1200 psi. The initial pressure can be maintained at 60 – 70 psi using the adjustment regulator and manual valve. After that, we set the valve voltage (symbolized by \(V_{valve}\)) step by step from the DAC module. When the valve is open, the gas flow rate through MFM can be read by MFM in sccm and by ADC module (user interface) in volt (symbolized by \(V_{flow}\)). The data recorded with a vacuum condition and non-vacuum (atmosphere pressure) condition inside the cyclotron chamber. The displayed data result are presented in Figures 3, 4, and 5. Figure 3 explains the \(V_{valve}\) vs \(V_{flow}\) with two different initial pressures which are 70 psi and 75 psi at a vacuum condition. The data show that the lower initial pressure, the higher \(V_{flow}\) obtained. Figure 4 shows that the \(V_{flow}\) in the vacuum condition is higher than those in non-vacuum condition. The different initial pressure has a small effect in \(V_{flow}\) in non-vacuum condition as shown in Figure 5. These data described that initial pressure affects the \(V_{valve}\) and \(V_{flow}\) in vacuum condition. In addition, the vacuum level affects the \(V_{valve}\) and \(V_{flow}\) in these experiments; however the vacuum level did not record. So, we cannot estimate the value of a vacuum that significantly affects the flow of the gas.

![Figure 3](image)

Figure 3. The \(V_{valve}\) vs \(V_{flow}\) at initial pressure variation of 70 psi and 75 psi in vacuum condition.
Figure 4. Comparison between vacuum pressure and atmosphere pressure for $V_{valve}$ vs $V_{flow}$ curve.

Figure 5. The effect of the initial pressure variation to the $V_{valve}$ and $V_{flow}$ in a non-vacuum condition.

The replacement of PSV by EVR 116 is to maintain the stability of the gas flow into the head of ion source. The percentage opening valve can be set by giving a certain voltage. It can be seen from the experiments that the valve voltage is not linear with the gas flow. This characteristic called installed characteristic for a control valve. This characteristic still needs further study and experiments to understand the performance of the system and to design a reliable operating system. Understanding of system performance is essentially to maintain the stability of the gas flow and the vacuum level not more than $10^{-6}$ torr. A good vacuum stability is expected to avoid damage to the components in a vacuum. A good vacuum stability is expected to avoid the damage of the component in the vacuum chamber.

The other recorded data in these experiments is gas flow in sccm unit (symbolized by $F_g$) which is displayed on MFM LCD. These data used for calibration of MFM by making a regression curve as shown in Figure 6. The coefficient regression for vacuum and non-vacuum conditions is 0.99. Similarly, Figure 7 describes $V_{flow}$ vs $F_g$ at different initial pressure 70 psi and 75 psi. It means that the linearity
of $V_{\text{flow}}$ in sccm unit v.s $F_g$ in mV unit indicates that MFM function properly. In Figures 6 and 7, it can be seen that to maintain the gas flow in the condition 5 – 10 sccm, the value of $V_{\text{flow}}$ can be maintained in the 500 – 1000 mV.

![Regression curve of $V_{\text{flow}}$ v.s $F_g$ at the initial pressure of 70 psi in vacuum and non-vacuum condition.](image)

**Figure 6.** Regression curve of $V_{\text{flow}}$ v.s $F_g$ at the initial pressure of 70 psi in vacuum and non-vacuum condition.

![Regression curve of $V_{\text{flow}}$ v.s $F_g$ at the initial pressure of 70 psi and 75 psi.](image)

**Figure 7.** Regression curve of $V_{\text{flow}}$ v.s $F_g$ at the initial pressure of 70 psi and 75 psi.

The result of this experiment has shown the influence of any attached devices in the gas flow system to the head of ion source. The main parameter that should be considered are the opening voltage of the valve EVR 116, the voltage given MFM as feedback, initial pressure before gas passing through EVR 116, and also the real-time vacuum level condition.

4. **Conclusion**

From this experiment, three parameters must be controlled and monitored to optimize the gas flow system. These parameters are initial pressure before gas passing through EVR 116, voltage valve EVR 116, and vacuum level. By controlling and monitoring those three parameters, it is expected to maintain the stability of the beam current of DECY 13. Besides, calculation of the gas flow during a cyclotron operation also needs to be done to provide stability and beam current continuity.
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