RUSSIAN ACADEMY OF SCIENCES
PETERSBURG NUCLEAR PHYSICS INSTITUTE

PHENIX Muon Tracking Detector Gas System

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Gatchina 2005

УДК 539.107.4

Система газообеспечения мюонного трекового детектора в эксперименте PHENIX

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Аннотация

Описано устройство и основные принципы работы рециркуляционной системы газообеспечения детектора MuTr в эксперименте PHENIX [1]. Система обеспечивает детектор газовой смесью ($Ar + 30\%CO_2 + 20\%CF_4$) и стабилизирует давление в детекторе. Автоматизированная система контроля и съёма данных защищает детектор в случае аварийных ситуаций, накапливает информацию с датчиков температуры, анализаторов CO_2, O_2 и H_2O.

Abstract

The Muon Tracking Detector gas system was designed and fabricated to supply $Ar + 30\%CO_2 + 20\%CF_4$ mixture to the PHENIX [1] Muon Tracking (MuTr) chambers at a controlled pressure. This system can regulate the flow rate of the mixture while monitoring mixture temperature, pressure, and CO_2, oxygen and moisture content. A computer data acquisition system collects and logs the gas system operating parameters while providing a means of remotely controlling system solenoid valves and flow.

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1. Introduction

The main task of the MuTr gas system (Fig.1) is to provide a pure Ar+30%CO_2+20%CF_4 mixture to the MuTr chambers (North and South arms) at the chosen operating pressure. Refer to Table for a list of gas system parameters.

As the prototype of MuTr gas system scheme, the STAR TPC gas system scheme was taken [2]. The MuTr system operates nominally as a closed circuit gas system with the majority of mixture recirculating through the detector. The negligible amount of the mixture is recirculating through the bypass lines of North and South MuTr arms. During normal operation a small amount of fresh mixture is added through Hastings mass flowmeters (FM1, FM2,FM3) and an equivalent quantity of the existing mixture is vented in the form of leak and flow through the Fairchild 10212BP back pressure regulator BPCV1 and Matheson 8112 indicating mass flowmeter FM4. The gas system can also operate in an open configuration for purging.

Table. Performance of gas system

Mixture	Ar+30%CO_2+20%CF_4
Small compressors output pressure	60” WC
Mixture supply pressure	2.0” WC
Mixture return pressure	0.33(+/-0.06)” WC
Recirculation flow	5-10 l/min
Purge Mixture flow	10 l/min
Make-up mixture flow	0-5 l/min
Oxygen content	< 300ppm
Water content	<10ppm

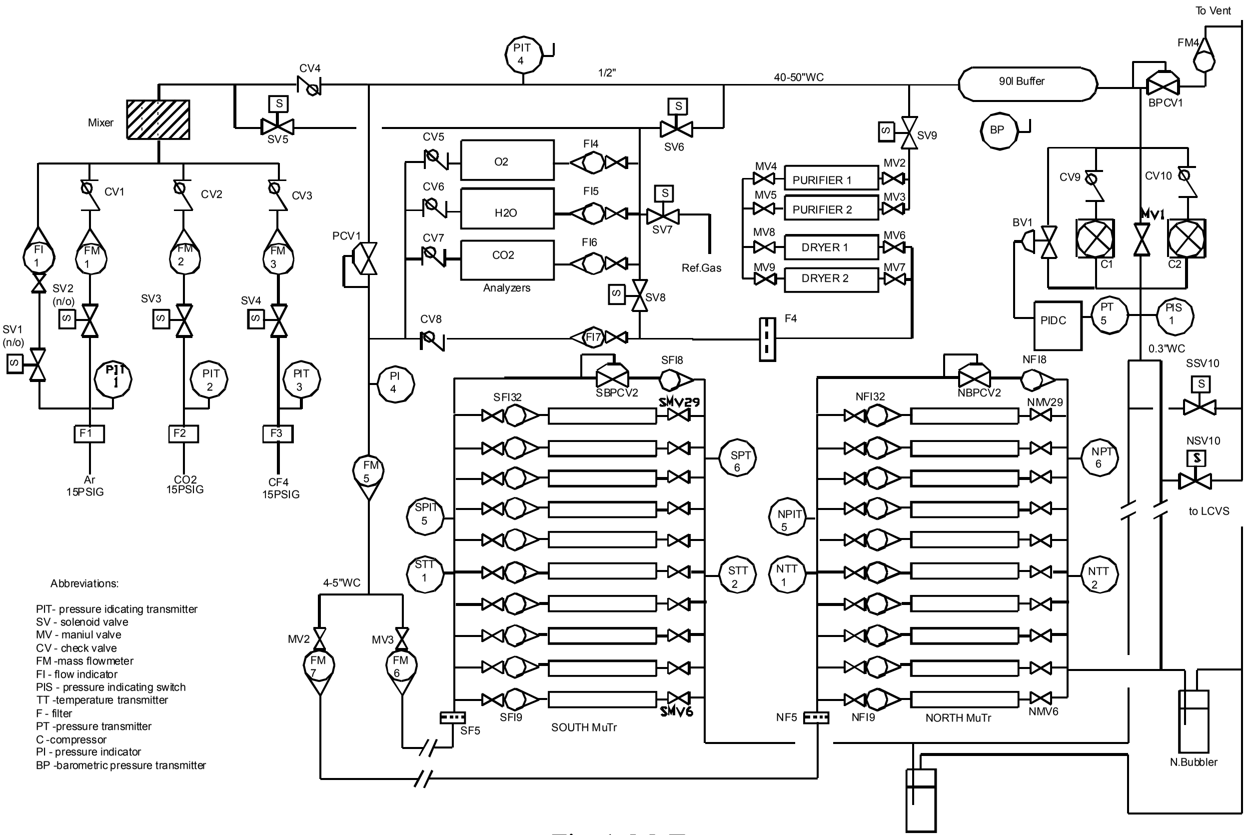

Fig. 1. MuTr gas system.

The mixture circulation rate through the ADI small membrane compressor is 10 l/min at 60” WC. The gas system contains two compressors (C1, C2), one active and one spare. The mixture from the compressor goes to the supply line through the check valves CV9 or CV10. The 60” WC output pressure from the compressor is reduced to 2.0” WC by Fairchild 10212 pressure regulator PCV1 and supported with back pressure regulator BPCV1. The return gas manifold is maintained at 0.33” WC above atmospheric pressure by Dwyer 616-1 differential pressure transmitter (PT5) and Tescom ER3000 electronic pressure (PID) controller that operates ASCO bypass valve BV1. A second bypass valve MV1 is manually adjusted to enable the automatic control loop to be used within its optimum range.

The Matheson 8112 indicating mass flowmeter FM5 measures the recirculating flow. The measurements of the fresh mixture (FM1, FM2 and FM3) and flow through the Matheson 8112 indicating mass flowmeter FM8 give a possibility to estimate the detectors leakage. Two Matheson 8112 indicating mass flowmeters FM6 and FM7 are measuring the recirculating flows for North and South MuTr arms.

The purity and composition of recirculating mixture is monitored using Teledyne 3010TA oxygen, California Analytical 200 carbon dioxide and Kahn OEM humidity analyzers. A fraction of the recirculating mixture can be passed through a purifier and dryer to remove moisture and oxygen as needed.

A computer driven data acquisition/control system based on the National Instruments SCXI electronics monitors all of the process variables. The computer system tracks the process variables which exceed the predefined limits and initiates corrective actions. In addition, a relay system based on the Dwyer A3000 pressure indicating switch is used to protect the detector from the overpressure or the underpressure in case of computer control system failure.

A rapid change in atmospheric pressure is typical preceding storms and hurricanes for Brookhaven National Laboratory area. To assure that the MuTr chambers follow a fast rise in atmospheric pressure 90 liters buffer was used. But if its gas volume is not sufficient, a relatively large flow of inert gas (Argon) can be admitted into the chambers. The vent lines, associated valves and bubblers are sized to allow the rapid venting of the MuTr chambers mixture to prevent a high internal pressure in case of fast barometric pressure fall.

2. General description.

2.1. Gas system layout.

The MuTr gas system occupies 2 racks: the gas rack and the electronic one. Both racks are located in the PHENIX mixing house. This region is divided by two areas: gas racks area and area for electronic racks. The gas rack is located together with another gas system racks that use the different flammable gases. As this area is built to Class 1 DIV 2 standards, all electrical components of MuTr gas system are explosion proof or placed into the boxes purging with the dry Nitrogen gas.

The electronic rack includes PC, SCXI readout electronics, power supplies, mass flowmeters power supplies, solid state relays boards and oxygen and water analyzers electronics. The distance between the racks is about 10 meters.

The distance between the gas rack and South MuTr chambers is 50 meters. The North MuTr chambers are located at 70 meters distance from the gas rack.

2.2. Gas supply

PHENIX experiment is equipped by a distribution gas systems located on the gas pad which supply the different gas systems with pure gases. The MuTr gas rack is supplied with the filtered Argon, Carbon Dioxide and Freon 14 at 15 PSIG pressure. Pressure levels of these gases are monitored with the control/data acquisition system to inform the shift crew in case the input pressure drops below the operation pressure of the mass flow controllers (typically 10 PSIG).

2.3. Mixture preparation

Hastings calibrated mass flowmeters FM1, FM2 and FM3 controlled by a computer prepare a correct gas mixture making use the estimated mixture composition data and California Analytical 200 CO_2 infrared analyzer. To have a stable mixture composition over a long operating period, the mass flowmeters are combined as follows: Argon (FM1) mass flowmeter is a master and CO_2 (FM2) and CF_4 (FM3) are the slaves. This means that FM1 output signal is a control signal for FM2 and FM3. If the Argon flow through FM1 is changed, the FM2 and FM3 flows will be changed respectively to keep the mixture composition stable. Data acquisition system measures all flows and calculates the CO_2 and CF_4 contents in the mixture. It will then inform the shift crew if they exceed the limits through the system alarms.

2.4. Pressure control

As mentioned above, the output from the compressor is 10 l/min at 60" WC in the recirculation mode. The back pressure regulator (BPCV-1) in the outlet line maintains the 60" WC pressure independently of compressor output and provides an exhaust to make up for the influx of fresh gas. The pressure level of 2.0"WC is controlled by the pressure regulator PCV-1 upstream of the MuTr chambers. The MuTr exhaust pressure, measured at the return gas manifolds may be maintained in the range of 0.2-0.4"WC by a Tescom ER3000 electronic pressure PID controller. A Dwyer 616-1differential pressure transmitter (PT-5) with the range of 0-3"WC produces a 4-20 mA output that the PID controller compares to a set point value of 0.33"WC pressure. If the transmitter signal is different from the set point, the controller sends a pneumatic output signal to the ASCO air operated bypass control valve. The bypass shunts flow from the compressor discharge line directly back to the compressor intake. Opening the bypass valve causes the MuTr's exhaust pressure to rise and closing it makes the pressure fall. A second bypass valve (MV1), manually adjusted during the initial system set-up, enables this automatic control loop to be used within its optimum range.

There are additional levels of control in the event the primary pressure control loop fails or is insufficient to keep up with external pressure changes. When the internal MuTr pressure, as measured by NPT-6 and SPT-6, is more than 1.0" WC above ambient, the gas control system will close the solenoid valves SV2, SV3 and SV3 in the gas supply lines and open the vent valves NSV10 and SSV10 allowing the MuTr to vent directly to the atmosphere. If the pressure exceeds 1.5" WC, the excess MuTr mixture will vent to the atmosphere through the bubblers as well. This system of backups protects the MuTr from overpressure due to mass flowmeter malfunction, rapid drop of atmospheric pressure and a failure of the back pressure regulator.

The detector is also protected from underpressure. If there is a rapid rise in atmospheric pressure or, effectively, a fast drop of the MuTr internal pressure, the dual set point Dwyer differential pressure transmitters (NPT6, SPT6) in the return manifold will trip as the pressure falls below 0.1" WC, causing an audible and visual alarm. If the pressure at NPT6 and SPT6 falls further, to 0.05” WC, a second set point trips and the computer control system will stop the compressor, pass inert gas through FI1 flow indicator by opening solenoid valve SV1 and maintain it in the open position to supply an additional 5 l/min of inert gas. This system can keep up with 6 mBar/min atmospheric pressure increase rate.

An extra protection level of MuTr under- or overpressure is provided by another pressure-indicating switch (PIS1) with dual setpoints installed in the return manifold. This switch is not connected to the computer control system; instead it is hardwired to perform the same functions as the computer control system in the event of falling or increasing internal detector pressure.

The MuTr is also protected from pressure extremes in case of power failure. A power failure will cause solenoid valves SV1, SV2, NSV10 and SSV10 to open or remain open, and will cause SV3 and SV4 to close, resulting 5 l/min of inert gas to flow through the detector. This flow rate is adequate to assure that fluctuations in the atmospheric pressure will not result in an excessive external pressure in the field cage and the MuTr gas will not be contaminated by air being drawn back in through the exhaust vent.

2.5. Mixture sampling

The quality of mixture can be measured at three points of the gas system:

- fresh mixture content (SV5);
- compressors output (SV6);
- purifier/dryer output (SV8).

During the normal operation mode the analyzers are connected to the compressors output. To measure the oxygen content in the mixture we are using Teledyne 3010TA Oxygen trace analyzer. The water content is measured with Kahn OEM ceramic humidity analyzer with the range of 0-1000 ppm. California Analytical 200 carbon dioxide infrared analyzer with the range of 0-100% is used to adjust the mass flowmeters to have the correct fresh mixture composition and to check the MuTr chambers mixture after theirs purging.

The additional sampling point (SV7) is used to calibrate the analyzers with the reference mixture.

2.6. Mixture purification

To reduce the oxygen and water content in the mixture we are using the commercial purifiers and dryers (Agilent BOT-4 oxygen purifiers and BMT-4 humidity dryers).

2.7. Data acquisition and control

The gas system is controlled by a PC-based DAQ subsystem. All sensors are read by National Instruments SCXI-1200 DAQ module using analog multiplexer SCXI-1100. Analog outputs of the DAQ module are used to control flowmeters. Solenoid valves and compressors are controlled by SCXI-1163 isolated digital output module using solid state relays.

The main computer software [3] has been developed with Borland Delphi for the Windows platform. It provides reliable data acquisition, alarm conditions handling and manual control of the gas system. Also, all events and process variables are logged. The software is divided by multiple processes that communicate making use of special operating system kernel objects.

The main process reads all sensors values and passes them to other processes. In order to make DAQ more reliable, it has been divided by two threads: one for the Graphical User Interface (GUI) and one for the data acquisition. The GUI thread shows all gas system parameters including valves state in the main window and handles operator actions. The DAQ thread acquires all the process variables, writes them into shared memory and checks alarm conditions. Every alarm setting contains alarm threshold, alarm message and control template, which indicates alarm set and release action for every controlled device, e.g. valve or compressor. This allows user to have a very flexible configuration of system behavior.

The second process, Data Writer, reads current process variables acquired by the main process and writes them to the MS Access database. Using a separate process for this critical operation improves overall software stability and decreases response time for gas system events.

All data from the gas system are kept in MS Access database, giving one a possibility to use native MS Access tools for converting and analyzing these data. Besides, this simplifies dramatically access to the certain data in a huge database (for example, 3.5 month database has approximately 200 thousands of records). Sometimes it is useful to get fast results and charts from the database during the gas system operation. A special tool for working with the database has been developed. This program (DB Viewer) provides visualization of the data from any system sensor at any given date for one of three periods (day, week or month). It also allows user to convert data from the database to tab-delimited text file for external analysis. There is a possibility to read all system parameters with 1 second period, which is useful for fast reaction to the gas system alarms. Nevertheless the data is written to the database once per minute (if no alarms happen) to reduce database size.

3. Gas system experimental results

The first MuTr gas system operation was during the RHIC experimental run 4 (January – May 2004). It showed the good parameters and provided the correct mixture content at the stable pressure to the MuTr chambers during the whole run period. For all operation time the make-up flow was 4.1 l/min and the recirculation one - 6.0 l/min. The measured detector leak rate was 3.5 l/min.

It is very important during the gas system operation in the recirculation mode to have the stable differential pressure of MuTr chambers independent on the barometric pressure fluctuations. According to the Fig. 2 and Fig. 3 we can conclude that PID controller supported the pressure setpoint level of 0.33“ WC with +/-0.06” WC stability at the detector output manifolds, although the barometric pressure varied in the range of 987-1027 mBar for one month operation.

The mixture content was very stable (see Fig. 4 and Fig. 5). Calculated CO_2 and CF_4 content in the mixture are shown in Fig. 5. The software calculates these parameters using the FM1, FM2 and FM3 mass flowmeters readings (Fig. 4). The carbon dioxide analyzer was only used at the beginning of operation to adjust the mixture content of fresh mixture prepared by the FM1, FM2 and FM3 mass flowmeters.

During all gas system operation we did not use the purifier and dryer. But according to Fig. 6 the water content was in the range of 2.2 – 3.4 ppm. The oxygen content varied in the range of 178-210 ppm as shown in Fig. 6. This oxygen level is normal for the MuTr chambers therefore purifier was not used.

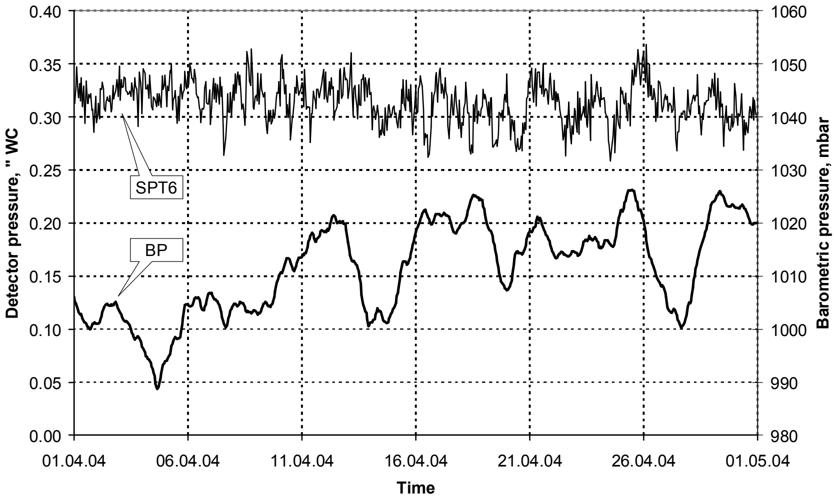

Fig. 2. South MuTr output manifold and barometric pressures chart.

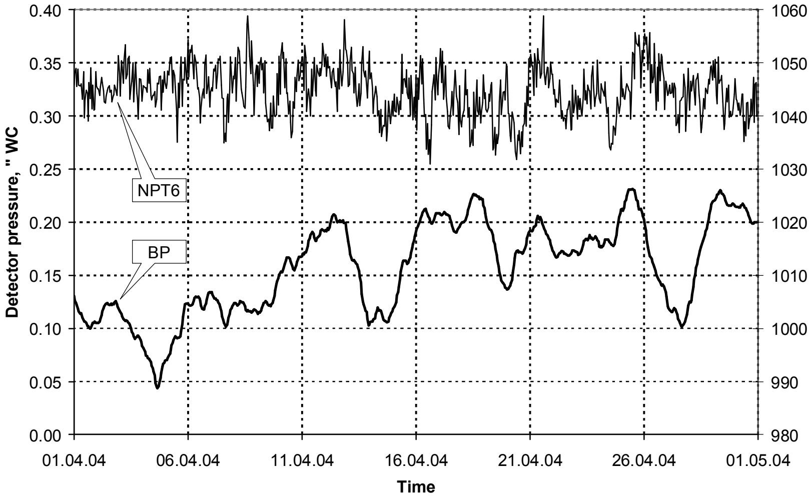

Fig. 3. North MuTr output manifold and barometric pressures chart.

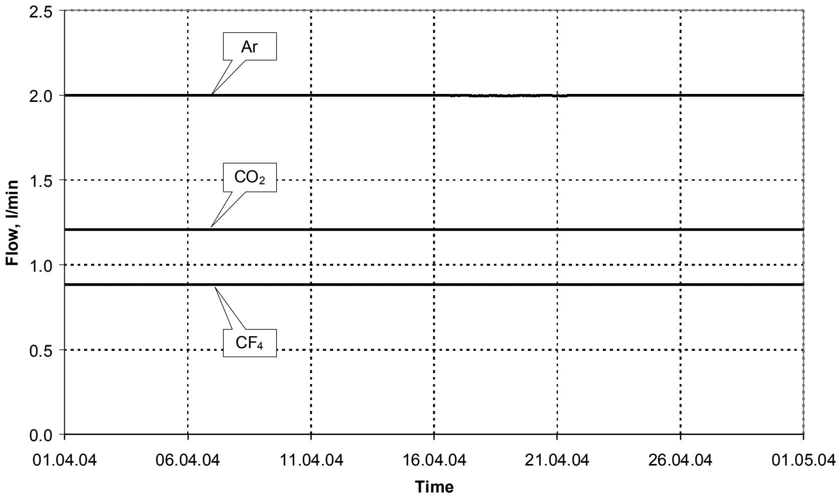

Fig. 4. Ar, CO_2 and CF_4 flows.

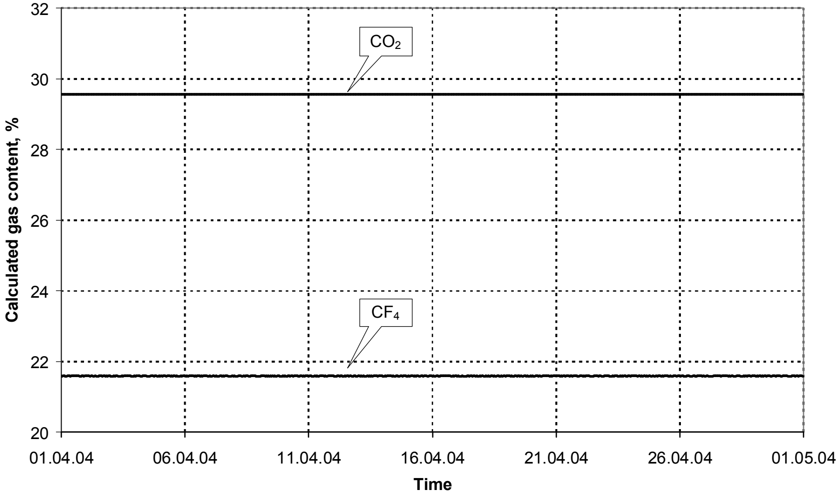

Fig. 5. CO_2 and CF_4 content in the mixture.

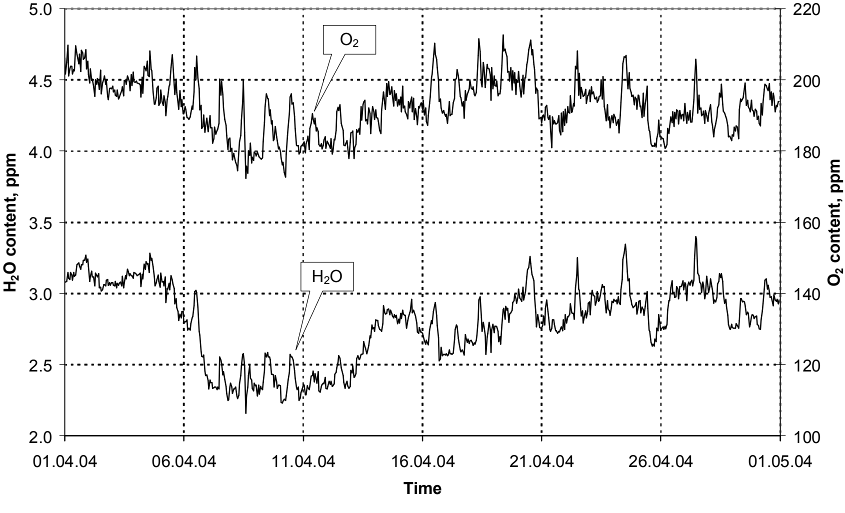

Fig. 6. H_2O and O_2 content in the mixture.

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