PREFACE

COMPASS (Common Muon and Proton Apparatus for Structure and Spectroscopy) is a fixed target experiment in the Super Proton Synchrotron (SPS) of CERN. It has been running since 2001. The purpose of the muon program is to study the spin structure of a nucleon with high intensity 190 GeV/c muon beams. With a dilution refrigerator the polarized target material is kept at a temperatures 50 - 300 mK. The dilution refrigerator at the COMPASS experiment is the largest in the world for this kind of operation.

The dilution refrigerator of the NA58 Compass target is monitored and controlled with a Siemens Simatic S7-300 PLC (Programmable Logic Controller). The system has 18 digital input channels, 20 analog inputs, 2 analog outputs and 10 relay output channels. A Siemens CP 343-1 IT unit allows connection to an external Ethernet to improve the security of the system by extended accessibility of process data. The IT-CP unit makes it possible to monitor process data using a web browser and provides a possibility to send alarm messages by e-mail or through CERN email GSM gateway directly to mobile telephones.

The first part of this report contains a description of the dilution refrigerator and the second the functions of the IT-CP unit of the PLC system. Diagrams of the refrigerator and documentation on the code used for the PLC are attached in the appendixes A-F.

CONTENTS

PART 1

PART 2

APPENDIX A-F

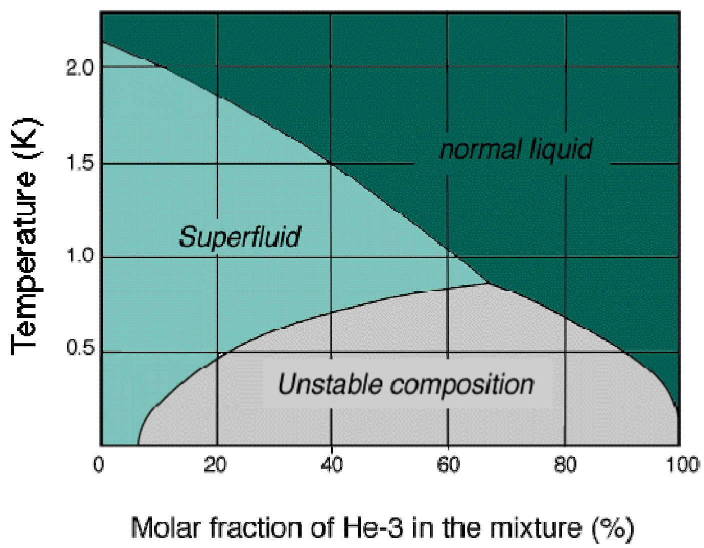
PART 1

DESCRIPTION OF THE CRYOSTAT

The cooling of the cryostat is based on the He-3/He-4 phase separation that occurs inside its mixing chamber. A cryostat of this type is continuously working and is capable of absorbing large heat loads during material polarization with microwaves. The construction is relatively simple. Large pumping system is needed for the high 50 - 300 mmol/s He-3 flow. The magnetic field of 2.5 T needed for the nuclear magnetic resonance used to determine the polarization has little effect on the performance. At these low temperatures the cooling power is large since the volume of the target material to be cooled down is big (about 1000 ccm).

He-3/He-4 phase separation

The principle of the dilution refrigerator is based on the properties of liquid mixtures of He-3 and He-4 at low temperatures. The graph shows the phase diagram of He-3/He-4 mixtures. The different regions have the following characteristics:

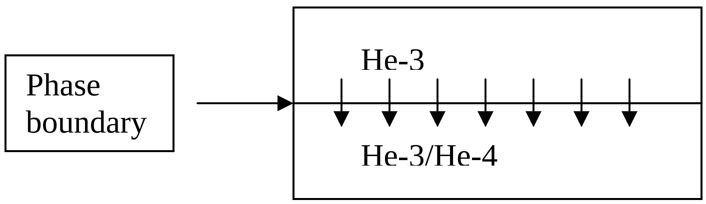


Normal fluid: Behaves like a Newtonian fluid. It has finite viscosity and is the only entropy carrying component in the system.
Superfluid: No viscosity and does not carry any heat.
Coexistence phase: Separation of two phases, the upper rich on He-3, the lower on He-4

The dilution refrigerator is based on the physical properties of the two phases which appear at the limit of the coexistence curve. He-3 has the remarkable property of finite solubility in He-4 at 0 K.

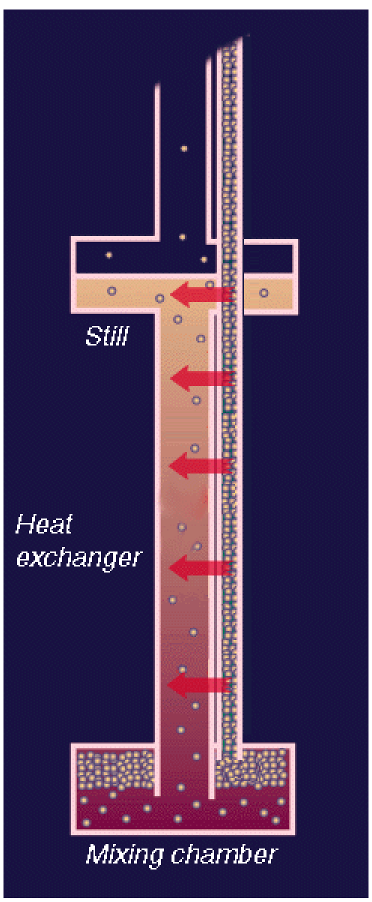
Cooling of the cryostat

The cooling inside the cryostat is produced by means of forcing He-3 atoms to move from the pure He-3 phase to the mixture of He-3/He-4. This is achieved with an large Pfeiffer roots pump system with pumping speed of 13 500 m^3/h. Due to the density difference between a pure He-3 phase and a He-3/He-4 mixture, the He-3 atoms will drift toward the top of the surface. The flow of He-3 atoms across the phase boundary pumps out heat from the surroundings.



Mixing Chamber

He-3 Circuit



The performance of the system depends strongly on how low temperature is achievable in precooling of the incoming He-3. Eight roots pumps (R1-8) connected in series generate the roots back pressure P3 and condensation pressure P10. The flow is measured with an electrical flow meter FM1. The liquid nitrogen trap with activated charcoal removes the oil and water vapor from the returning gas to avoid blocking of the cryostat. The gas flows through a needle valve NV2 works also as a flow impedance for condensation. The liquefying takes place in the copper tube inside the He-4 evaporator where the He-4 is kept at temperature 1.2 - 1.5 K. The condensation pressure (P10) of the incoming He-3 is kept sufficiently high for efficient liquefaction. The liquid He-3 passes several heat exchangers before entering the still with a temperature of 0.7 K. The liquid He-3 reaches the mixing chamber after flowing through 0.1 m^2 continuous and 12 m^2 step heat exchangers.

The figure shows the mixing chamber and the still of the cryostat. The incoming liquid He-3 flows through continuous and step heat exchangers.

Controlled devices/measured values:

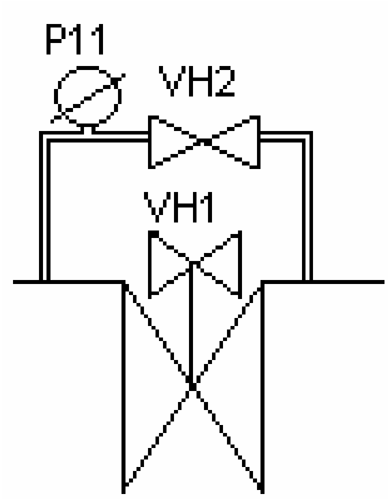
- Roots Electro Pneumatic Valve (VHB)
- He3 Flow (FM1)
- Roots Back Pressure (P3)
- Condensation Pressure (P10)
- Collector Line Pressure (MKS)
- Liquid N_2 Reservoir Level

Additional documentation in appendix A:

- Refer to the diagram He-3 Circuit
- Refer to the diagram LN_2 Filling System for Trap
- Refer to the Liquid Nitrogen Trap Fill Valve (VHLN) state diagram and table

He-3/He-4 Lines

In the mixing chamber, He-3 will be mixed with the He-3/He-4 dilute phase as described above. Due to an osmotic pressure gradient the He-3 will tend to drift through another series of heat exchangers back to the still. From the still the He-3 vapor is removed by the pump system R1-R8. A Roots Electro Pneumatic Valve (VHB) between the roots vacuum pumps R6 and R7 is controlled by the PLC system. The still heater must keep a high enough temperature to achieve an acceptable rate of gas circulation in the system, thus external heating is required. This removal of He-3 from the still results in a pressure gradient between the mixing chamber and the still. The concentration of He-4 in this gas is ignorable because of the inertial behavior of He-4. The He-3 pumped out from the still passes through the main gate valve (VH1) at pressure P11. A security valve VH2 in parallel to the main valve. VH1 can be opened manually.



Main Gate Valve (VH1 and Bypass Valve (VH2)

During the precooling of the system, a diffusion pump is switched on in order to obtain vacuum inside the cryostat. In this operation mode, the still is the coldest part and the mixing chamber the warmest. Below the phase separation temperature, the mixing chamber temperature drops rapidly, resulting in a switch of sign of the temperature gradient between the still and the mixing chamber. External heating of the still will now take place to increase the gas circulation rate.

The main gate should not be opened in case of too high pressure difference between the two sides of the valve. A bypass valve can be opened manually in order to equalize the pressure difference between the two sides.

Controlled devices/measured values:
- Roots Electro Pneumatic Valve (VHB)
- Main Gate Valve (VH1)
- Main Gate Valve Bypass (VH2)
- Roots Back Pressure (P3)
- Evaporator Pressure (P12)
- Still Pumping Line Pressure (P11)

Additional documentation in appendix B:
- Refer to the diagram He-3/He-4 Lines
- Refer to the Operation of VH1/VH2 state diagram and tables

The horizontal and vertical screen lines

Thermal isolation is crucial for achieving temperatures below 1 K. Heat leaks are caused by radiation and conduction, mechanical vibrations and absorption from rf-fields. In order to protect the system from absorbing external heat, it is shielded by two layers of radiation shields, the inner one cooled down to a temperature of 4 K, the outer to 80 K. There are two screen cooling lines, one for the vertical shield and the other for the horizontal shield. The excess of cold He-4 gas drifting away from the separator cools down the shields. The He-4 gas returns after the cryostat to the Helium liquefier able to produce more than 100 l of liquid in an hour.

Controlled devices/measured values:
- Horizontal Screen Bypass (VH58)
- Vertical Screen Bypass (VH59)

Additional documentation in appendix C:
- Refer to the diagram Screen Lines
- Refer to the Vertical Flow Controller Bypass Valve VH58/Horizontal Flow Controller Bypass Valve VH59 table

Evaporator-circuit

If the pressure in a vessel of liquid He-4 kept at atmospheric pressure is reduced, some of the He-4 evaporates and cooling results. The evaporator is a bath of liquid He-4 kept at a temperature of 1.5 K. The inlet is liquid He-4 from the separator flowing into the evaporator. The flow is controlled by the needle valve NV1. The level of liquid in the evaporator (measured with superconducting level gauge DLG 200) is maintained close to the maximum in normal operation. The pressure in the evaporator (P12) must be kept lower than 0.1 bar. The He-4 gas is pumped out of the evaporator by means of a 2000 m^3/h roots pump (PR1) and a 630 m^3/h rotary pump (PP1). The pressure in the He-4 return line is monitored with P63 and the flow after pumps PR1 and PP1 is measured with flow meter FM60.

Controlled devices/measured values:

- He4 Flow (FM 60)
- Evaporator Pressure (P12)
- He4 Electro Pneumatic Valve (VEP70)
- 4He Roots (PP1)
- 4He Rotary (PR1)
- Evaporator Level (DLG 200)
- Liquid He Dewar Level

Additional documentation in appendix D:

- Refer to the diagram Evaporator Circuit

Separator-Circuit

The separator is supplied with liquid Helium through an electropneumatic control valve FCV 578 from the 2000 l buffer dewar. The separator is kept a little above atmospheric or the recovery line pressure. At this pressure the He-4 will liquefy around 4.2 K. The evaporating gas flows into the screen lines and the separator line and returns finally to the cold box. During precooling of the system, He-4 gas will flow into the evaporator through a needle valve (NV5). In normal operation liquid He-4 flows from the separator bottom to the evaporator through the needle valve (NV1) and to the cavity screen line through the needle valve (NV4). The rotary pump (PP1) keeps the temperature of the cavity around 3 - 4 K by evaporative cooling. The pressure in the cavity pumping line is monitored with P60.The flowmeter FM 52/53 indicates the molar He-4 flow in the cavity screen line.

Controlled devices/measured values:

- Separator Flow (FM54)
- Liquid He Dewar Level
- Liquid He Control Valve (NVL)
- 4He Roots (PP1)
- 4He Rotary (PR1)
- He4 Flow (FM 60)

Additional documentation in appendix E:

- Refer to the diagram Separator Circuit.

Vacuum-System

All the components of the cryostat are in an isolation vacuum. The SMC superconducting magnet and the dilution cryostat share the same isolation vacuum. The common vacuum pump system is composed of RVP12 rotary pump and ODP11 diffusion pump. The operation of the diffusion pump is not sensitive to the magnetic field, thus it is preferred to a turbo pump. In case of lost power to the diffusion pump or detection of deteriorating vacuum measured with cold cathode gauge IKR, an emergency pump system PTI and PPI powered from CERN 48VDC can be automatically started by the PLC system. The emergency pump can also be operated manually.

Controlled devices/measured values:

- Isolation Vacuum (IKR)
- Vacuum Diffusion Pump
- 48 V Emergency Vacuum Turbo Pump
- Gate valve to isolation vacuum (VH20)

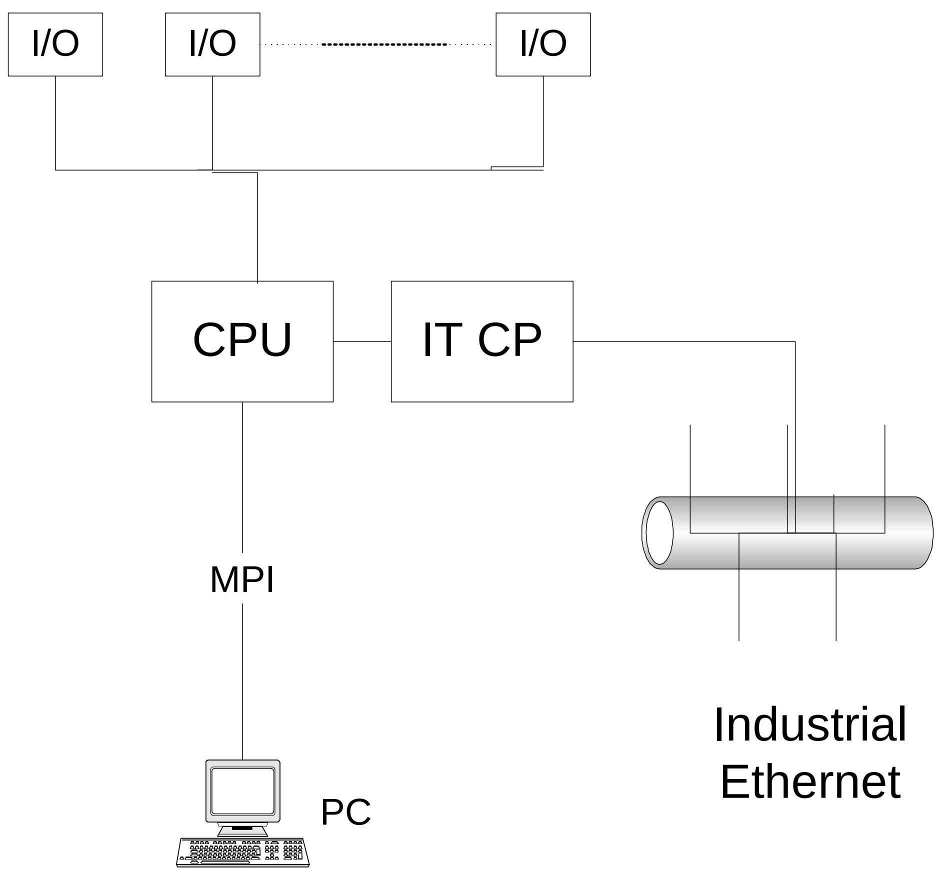
Additional documentation in appendix F:

- Refer to the diagram Vacuum Lines
- Refer to 48 V emergency turbo pump and its gate valve to isolation vacuum (VH20) state diagram and table

PART 2

FUNCTIONS OF THE IT-CP UNIT OF THE PLC SYSTEM

The dilution refrigerator of the NA58 Compass target is monitored and controlled with a Siemens Simatic S7-300 PLC (Programmable Logic Controller). The CPU module has a Profibus connection to control the distributed I/O subsystems and MPI connection for programming from a PC. Siemens CP 343-1 IT unit allows connection to an external Ethernet to improve the security of the system by extended accessibility of process data. The IT-CP unit makes it possible to monitor process data from dilution refrigerator via the CERN intranet or even from external Internet. It also provides a possibility to send alarm messages by e-mail or through CERN email GSM gateway directly to mobile telephones.



HTML process monitoring

The process data display and input are incorporated into an ordinary HTML page by means of S7 applets. The applets allow reading and writing to any S7 station via the IT-CP. They can be straightforwardly integrated in the html-code. The web-browser in which the applet was started is responsible for the execution of the applet. The applet is activated and a frame is assigned to it within the current HTML-page. When requested the IT-CP passes the jobs to the relevant module on CPU. The HTML code is transferred to the IT-CP by the use of File Transfer Protocol (FTP), and is saved in the non-volatile memory of the module. Even more sophisticated web pages can be implemented using Java source code. However one should keep in mind that too complicated code will require a lot of network capacity. Depending on the type of web-browser used, there is a maximum number of applets allowed to use within one call.

On the web-site http://na58plc588.cern.ch/ the applets are embedded in the HTML-page by use of the following type of call:

```
<APPLET CODE="de.siemens.simaticnet.itcp.applets.S7GetApplet.class"
CODEBASE="http://na58plc588.cern.ch/applets/"
   ARCHIVE="http://na58plc588.cern.ch/s7applets.jar,%20s7api.jar" width="50"
HEIGHT="32" NAME="He4_Roots_On_Signal">
       <PARAM name="RACK" value= 0>
       <PARAM name="SLOT" value= 2>
       <PARAM name="CYCLETIME" value= 10000>
       <PARAM name="BACKGROUNDCOLOR" value=0xFFFFFF>
       <PARAM name="LANGUAGE" value="en">
       <PARAM name="DEBUGLEVEL" value=1>
       <PARAM name="EDIT" value="true">

       <PARAM name="VARTYPE"     value=2>
       <PARAM name="VARCNT"      value=1>
       <PARAM name="VARAREA"     value=0x84>
       <PARAM name="VARSUBAREA"  value=14>
       <PARAM name="VAROFFSET"   value=0>
       <PARAM name="FORMAT"      value="\X(2,Running,Stopped)">

</APPLET>
```

Remarks:

- If the debug level is set to 1 all messages will be displayed, otherwise only default error messages are shown.

- Pay attention to what kind of values are assigned to the parameters VARAREA, VARTYPE and FORMAT. They must be compatible. For instance in the example above, VARAREA value=0x84 means that the read out is a data block in the memory area. VARTYPE value=2 means that the value is a byte, while "FORMAT" value="\X(2,Running, Stopped)" checks if bit number 2 in the byte (consisting of bits numbered from 0 to 7) is 0 or 1. In the first case the string "Running" is printed, in the latter it is "Stopped".

For a further description of the parameters, refer to the Siemens Simatic Net IT-CP manual ("Instructions for the CP 343-1 IT and CP 443-1 IT").

For security reasons the system is in a **read-only mode which denies any attempt of modifying parameters from the web**.

Further development of the web pages

An improvement of the web pages would have been to show a graphical display of the history of the different parameters. However this is imposing a task of where to store the process data history.

Sending process alarms by e-mail

The IT-CP unit is implemented to operate as an e-mail client supporting the simple mail transfer protocol (SMTP). An e-mail connection is established between the CPU315-2 DP and the IT-CP. The e-mail server is the CERN-server smtp.cern.ch. The absolute (numeric) IP-address has to be used in the configuration for the mail server since the system fails to find the correct IP-number from the Domain Name Server (DNS).

For sending the e-mail, the predefined S7-blocks AG_SEND (FC 5) is used, which allows to send e-mail with a content less than 240 bytes. There is also possibility to send longer mails even with attached files with a different function block. Since the protocols used are connectionless, there is no guarantee that the e-mail arrives at the recipient.

It is recommended to try to send a test-mail from the IT-CP module to check that the e-mail is functioning correctly. This can be done from module hardware diagnostics tool from the programming PC of the PLC system. Successful sending of an e-mail indicates that the IT-CP is ready to send e-mails, a connection that can be used by user programs is established and that the recipient specified in the request is available. However, one cannot conclude anything about the status of the user program calling the function calls AG_SEND nor the time required from a mail being sent until it is received.

Security

One of the big advantages of the IT-CP system is obviously that the staff member can easily view the status from the system from their home computers or office computers. However this implies certain danger of misuse. In order to guarantee information security while accessing the process data, the supplier recommends password protection and use of other security mechanisms.According to the documentation there are possibilities for external access to the IT-CP-server that are implemented in secure ways. The major problem will nevertheless be to be allowed access through the CERN firewall. Because of the strong security mechanisms imposed to protect the local area network at CERN, it will be hard to obtain external access to the web page with the process parameters. Nevertheless, a firewall protection within the LAN is recommended due to the high number of users of the CERN network. Only authorized users should have access rights to the web pages from the LAN.