DAΦNE CRYOGENIC COOLING SYSTEM: STATUS AND PERSPECTIVES

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Abstract

The cryogenic system of DAΦNE has been continuously operating for 5 years with only few weeks of shut down per year, due to scheduled maintenance or faults. The paper describes the system and its status, along with a detailed fault analysis. The upgrades undertaken to increase the reliability of the entire system and the work to accommodate the second big DAΦNE experiment are also presented.

1 INTRODUCTION

In the original layout of the DAΦNE storage rings the cryogenic plant was needed for the cooling of several superconducting magnets. Subsequently there was an evolution in the status of the plant, both for the accelerator and for the cryogenic plant developments.

The main components of the plant are listed in the next sections, together with a description of the cooling process of the magnets. Then, all the faults related to the cryogenic plant since the year 2000 are taken into account, in order to investigate the plant performance in relation with DAΦNE operation. The future upgrades of the plant, needed to reach the final configuration, are also mentioned.

2 CRYOGENIC PLANT

The main experiments in the DAΦNE storage rings are KLOE and FINUDA, which exploit the longitudinal field of two large superconducting solenoid magnets.

Both magnets are cooled by a 4.5 K liquid Helium refrigeration system.

The layout of the cryogenic plant is shown in Fig. 1. The main components of the system are:

1) Helium Process Compressor, a KAESER FSB440 screw air compressor adapted for working with Helium. It compresses the warm gas (300 K) from ≈1.02 to ≈14 bar (max).

2) Helium Buffer Volumes, in which the low pressure gas before entering the compressor is stored. It consists of two steel cylinders of 34 m^3 each, working at a pressure between 1 and 13 bar.

3) Warm Transfer Lines, a couple of Stainless Steel seamless pipes which drive the high pressure (HP) gas from the compressor to the Cold Box and the low pressure (LP) gas from the Cold Box back to the compressor.

4) Cold Box, a LINDE TCF50 standard refrigeration system with few adaptations (see later). It has the following cryogenic capacities:
   Liquefaction rate: 1.14 g/s
   Refr. Capacity @ 4.45 K, 1.22bar 99 W
   Refr. Capacity @ ~ 70 K 800 W

5) Cryogenic Transfer Lines, for the gas transport between the Cold Box (which is placed outside the DAΦNE hall) and the magnets.

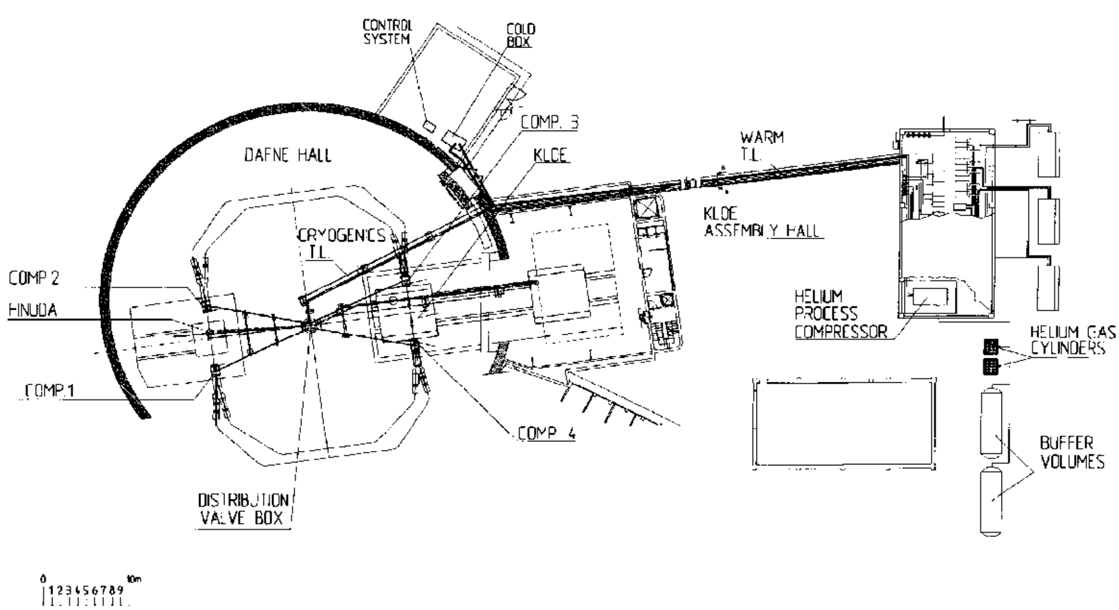

Figure 1: The DAΦNE Cryogenic System [1]

6) Distribution Valve Box, a cryogenic distribution system placed at the center of the DAΦNE hall, in the middle of the cryogenic transfer lines path. It provides the distribution of the different gas streams coming from the Cold Box to KLOE and FINUDA, but it is also designed and realized to distribute the Helium to four OXFORD INSTRUMENTS superconducting solenoid compensator magnets, (which compensate the magnetic field integral of the KLOE and FINUDA magnets, see Fig. 1).
7) Control System, a SIMATIC S7-400 PLC, connected to a remote personal computer with graphic interface. It manages almost all the valves of the system and gives information about the thermodynamic quantities related with the plant (pressures, temperatures etc.).

3 PROCESS DESCRIPTION

The cool-down process of the Cold Box is completely automatic. The control system is able to manage the plant in order to cool the Cold Box from room temperature to 4.5 K in about 3 hours.

The Cold Box has a standard Claude-Cycle design, with 2 turbines in series, 8 heat exchangers and one Joule-Thomson valve.

The most important modification with respect to the standard TCF 50 layout is the design of the cold side. Before the Joule-Thomson valve the gas flow is splitted in two parts, one passing in the Joule-Thomson valve and liquefying in a vessel, the other in a heat exchanger coil inside the vessel. This is needed to have gas at 3 bar and 4.5 K. Downstream the Cold Box the gas goes through the cryogenic transfer lines and reaches each magnet. Here there is, just before the cryostat vessel, a Joule-Thomson valve that allows the gas to liquefy.

Helium gas at intermediate temperature (≈50 K) for thermal shields cooling is supplied by the first turbine output.

So far, only the two big magnets (KLOE and FINUDA) have been cooled and energized.

KLOE is installed on the storage ring and is running since March 1999.

FINUDA has not yet rolled into the DAΦNE interaction region but it is now in its pit in the DAΦNE hall and connected to the cryogenic plant; the last cool-down took place in April 2002.

Only the two compensator magnets of KLOE have been installed. There are some problems in cooling these two magnets by means of the cryogenic plant, namely it is not possible to liquefy inside the magnet cryostat. The reason is not yet completely understood, but two possible causes are considered: first, the temperature of the gas at the end of the transfer line may be too high (due to the heat leaks in the path) for the production of liquid; second, the hole of the magnet Joule-Thomson valve may be too narrow to get the necessary flow.

Both these causes are taken in account, and some modifications are scheduled to overcome this problem (see later). At present the KLOE compensators are filled from standard liquid Helium dewars.

4 PERFORMANCE ANALYSIS

In 1997 the last installation tests of the plant have been performed and the KLOE magnet was cooled for the first time. At that time the magnet was located in a building adjacent to the DAΦNE hall. When, in 1998, the magnet was rolled inside the accelerator hall, the transfer line was modified consequently. In March 1999 the magnet was cooled and energized, and in September the experiment started the operation.

The analysis covers the period from January 2000 to May 2002. 1998/99 documentation is not accurate enough about the cryogenic faults, therefore it has not been taken into account.

From September '99 to spring 2002 the behaviour of the cryogenic plant is dependent on the overall efficiency of the KLOE magnet system, since the FINUDA magnet was energized only for few hours. A statistics about the faults related to the cryogenic plant is shown In Tab. 1.

False Quenches in the table are overvoltage signals in the quench detector device, that are not related with a real magnet quench but come from failures of the detector. In fact, so far, the magnet has never had a real quench. Voltage Dips are referred to the compressor mains. The Auxiliary Plants are the compressed air system (used for the valve actuators) and the water cooling plant (for the compressor and the turbines).

Most of the events, like auxiliary plant faults, KLOE PSU faults, voltage dips and false quenches, are not real cryogenics faults. However, these events are still taken into account since they originate troubles in the cryogenic plant. An important part of the downtime is due to the cryogenics restart operations following these faults.

Table 1. January 2000 – May 2002 cryogenic related faults statistics.

	Cryogenic Faults	Control System Faults	False Quenches	Voltage Dips	Auxiliary Plants Faults	Kloe PSU Faults	Not Ascribed Faults
Fault Events	5	10	2	9	8	4	5
Total Downtime (+ delivery time) [h]	40.0	42	48.5	79.0	91.5	38.5	20.5
Mean Downtime [h]	8.0	4.2	24.3	8.8	11.4	9.6	4.1

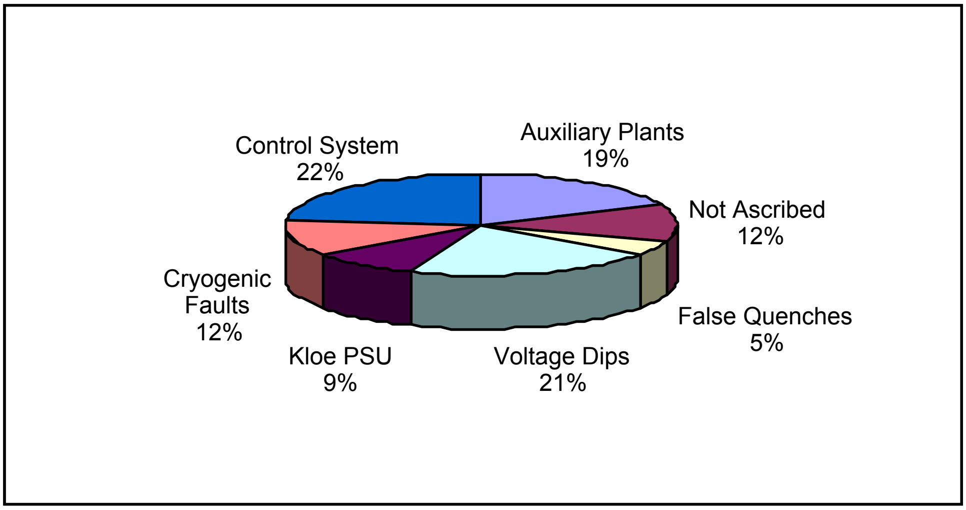

Figure 2: Relative weights of the number of events.

Real cryogenic faults are those listed in the first two columns of Tab. 1. The five Cryogenic Faults have been: a problem in a cryogenic valve, a Helium overtemperature in the KLOE inlet (two times), a problem with the compressor fan and a turbine overspeed. The Control System Faults were communication failures between the hardware electronics of the system and the PC.

Apart from the valve malfunctioning, the cryogenic faults are related to the managing of the plant in some particular conditions: a turbine overspeed can occur, for instance, when starting to cool down FINUDA while KLOE is kept cold. In this situation the request of Helium for the thermal shields suddenly increases, lowering the pressure at the output of the first turbine, increasing therefore the turbine speed.

The relative weights of the number of events are shown in fig. 2, which points out the contributions of the control system faults, the auxiliary plants faults and the voltage dips. However, if one considers the average downtime per fault, also the contribution of the false quenches is significant. To this purpose we are waiting for new quench detector boards from OXFORD Instr.

5 CRYOGENICS UPGRADES

The next shut down of the DAΦNE accelerator is scheduled in fall 2002. Several operations and upgrades are foreseen:

- ♦ Standard maintenance of the compressor and the Cold Box with cleaning of the KLOE and FINUDA magnet cryostats (including transfer lines) with pure Helium.
- ♦ Roll-in of the FINUDA magnet. Consequently, the FINUDA cryogenic transfer lines must be modified. Disconnection of the existing line and reconnection to the magnet cryostat will be performed.
- ♦ Installation of the two compensator magnets, one on each side of FINUDA experiment. These magnets were modified by OXFORD Inst. in December 2001. The 1 mm diameter Joule-Thomson valves have been replaced by 6 mm diameter new ones.
- ♦ Installation of new cryogenic transfer lines from the Valve Box to the compensator magnets. They are flexible transfer lines built by NEXANS (Germany), with an intermediate thermal shield. A small part of the cold Helium flows in the inner tube is forced to return in the thermal shield, then heated at room temperature and sent back to the compressor. The specification asks for a Helium temperature in the shields always below 25 K. In such a way the thermal power dissipated in the inner tube never exceeds 0.02 W/m.

6 CONCLUSIONS

In the period January 2000 – May 2002 the DAΦNE accelerator complex has been running for 565 days. The cryogenic plant had 15 real faults (cryogenics + control system) which caused less then 4 days of overall downtime. Other 28 faults, which stopped the cryoplant but were originated by other equipment, determined about 11 days of machine downtime.

At the moment KLOE and FINUDA are cooled by the cryogenic plant while the two KLOE compensators are cooled with helium from dewars. After the next machine shut down FINUDA and all the compensator magnets will be on the beam, and all six magnets will be cooled by the cryoplant.

7 REFERENCES

[1] M. Modena, “The DAΦNE Cryogenic System”, Rep. LNF-97/046 (IR), December 1997.