SUMMERY AND RESULTS OF THE CRYOPLANT OPERATION FOR HERA

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For about 15 years, leptons and protons collided inside the HERA particle accelerator with the intension of investigating the protons' inner structure. 646 superconductive electromagnets and 16 superconductive cavities had to be constantly surrounded by liquid helium to operate at a temperature of around 4 K. To ensure the helium supply of HERA's superconductive components a highly productive refrigeration plant was built.
In this paper we report on the experience gathered during nearly 20 years of operation of the refrigeration plants' 3 cold boxes and the corresponding 14 screw compressors together with the helium distribution system and the purification system.

INTRODUCTION

The construction of HERA (**H**adron-**E**lektron-**R**ing-**A**nlage) was started in 1984 and HERA began to operate as the largest synchrotron and storage ring (6.3 km ring circumference) on DESY site in November, 1990 [1,2]. Only two years later, in 1992, HERA's first two experiments, H1 and ZEUS, started collecting data to study the structure of protons and properties of quarks more accurately than ever before. HERA was closed down on June 30th 2007. The data gathered during this time will once give us a comprehensive overall picture of the proton and forces acting within it with the highest all-time accuracy. To reach the required collision energy of around 320 GeV 646 superconducting magnets for the protons and 16 superconducting cavities for either the electrons or the positrons have been used. The superconductive components had to be constantly surrounded and cooled by liquid helium to operate the accelerator at a temperature of 4 K [3]. To ensure the helium supply of HERA's superconductive components a huge and highly productive refrigeration plant was built. The construction of a plant of this scale in 1987 meant to break new ground on technology. Compressors, cold boxes, cleaning units and helium-dewars as storage for liquid helium and many other components belong to this plant. The operational history of this plant, related to availability, breakdown statistics, failure reasons, is the content of this paper.

LAYOUT AND REFRIGERATION-PROCESS

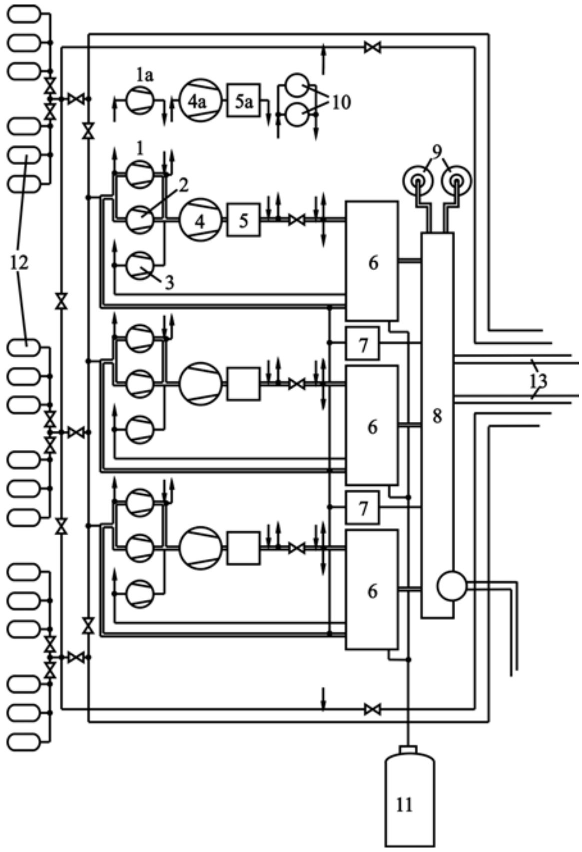

Figure 1 Flow diagram of HERA refrigerating plant. 1, 1a, 2, 3 Low pressure compressors; 4, 4a High pressure compressor; 5, 5a Helium dryer and oil adsorber; 6 Coldbox; 7 Helium heater; 8 Distribution box; 9 Helium Dewar; 10 Low temperature purifier; 11 Nitrogen tank; 12 Helium tank; 13 Helium transfer line.

The helium distribution system of the HERA accelerators and of the experiments in the experiment-halls consists of three equal units. Each unit consists of a cold box, three low pressure- and one high pressure compressor, several purify- and heater devices and a Helium Dewar to store liquid helium. In addition six large tanks for storage of gaseous helium with a pressure of up to 20 bar belong to each unit. Figure 1 shows the arrangement of compressors, purifiers, cold boxes and storage tanks. As compressors screw compressors are used. The Helium is firstly compressed to 4 bar and in a second stage to 18 bar. The plant comprises three equal sets of compressors each of which is made of three compressors operating in parallel in a first stage and a second combined high-pressure-stage. Additionally there is a spare compressor for the low- and the high-pressure-stage respectively which is able to replace every other unit within its pressure range while operating. In terms of prevention getting impurities in the refrigeration circuit an oil adsorber with an activated carbon filter and a pair of drier is connected to each high-pressure-stage. A low temperature purifier cooled by means of liquid nitrogen and a flow-rate of up to 1,000 g/s can optionally be connected to the helium output flow of each high pressure compressor. Furthermore each of the three cold-boxes has a set of internal adsorber to make sure turbines and refrigerating circuits are protected against impurities. In the Coldboxes the Claude-process is applied where expansion-turbines and counterflow heat exchangers are combined with helium expansion at low temperatures (Joule-Thomson-process). The total cooling capacity of three times 6.4 kW at 4 K, 22 kW at 40 K and a liquefaction capacity of 20 g/s are just a few decisive data of this remarkable plant to be mentioned. The flow scheme of a HERA cold-box inside is illustrated in figure 2.

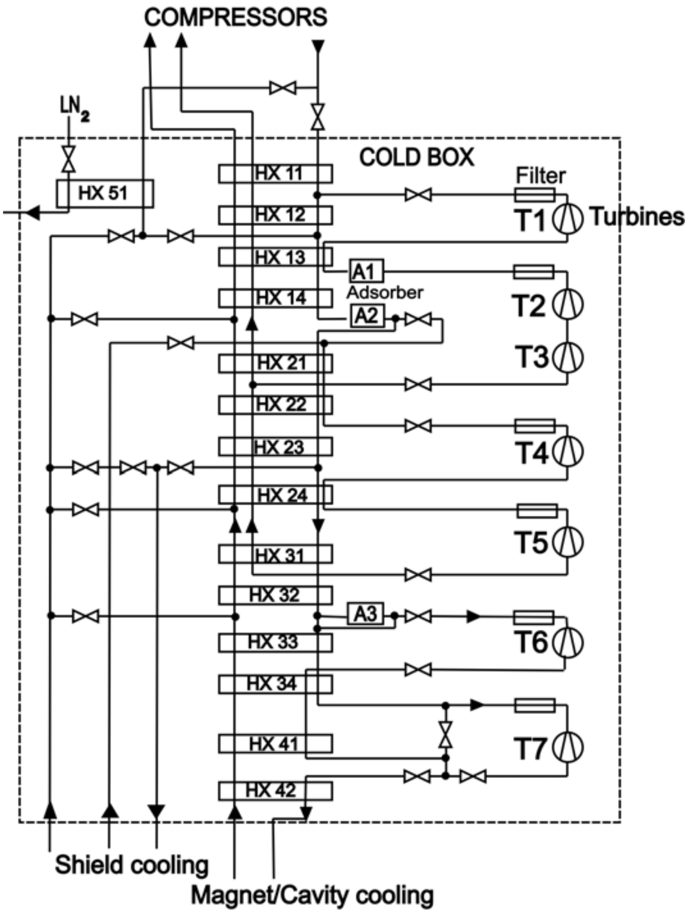

Figure 2 Flow diagram of HERA coldbox

Before entering the HERA storage ring the main flow of helium which is meanwhile expanded to 4 bar is piped through a Dewar filled with liquid helium to reach a constant temperature of 4.3 K by means of a heat exchanger. After the final expansion to 0.6 bar the helium vapour is led back from the storage ring to the low pressure compressor of the refrigeration plant. This low-pressure operation of the plant was initiated in July 1998 to be able to increase the proton energy to 920 GeV. Before the HERA accelerator was operated at a pressure of 1.05 bar with reduced proton energy of 820 GeV. To operate on low-pressure was only possible due to the budgeted overcapacity of the HERA refrigeration plant. The total amount of helium within the refrigerating circuit adds up to 15,000 kg. Two Helium-Dewars can store 2,500 kg of liquid helium. The Dewars are actively included into the refrigerating process and are able to compensate heat if necessary. High quantities of helium that can suddenly emerge in case of a quench of the superconducting magnets are collected in storage tanks for warm helium outside the refrigeration plant.

AVAILABILTY, FAILURE STATISTICS AND TOUCHIING UP'S

Throughout 17 years of HERA-operation the refrigeration plant compensated the cryogenic loads of the HERA accelerator, the HERA experiments and temporarily the FLASH accelerator and other recipients with a corresponding availability of 98,7 %. Related to the availability of the refrigeration plant itself this value exceeds 99 %. Despite this high reliability in the functionality of the HERA plant it also has to cope with technical problems decreasing the availability. In the following a failure statistic over the last 16 years of HERA operation is given. Thereby the failures are subdivided into 5 categories: compressors, process computer, electrical power, water and pneumatic air of the refrigeration plant and its infrastructure. The failure statistic is displayed in the figure 3.

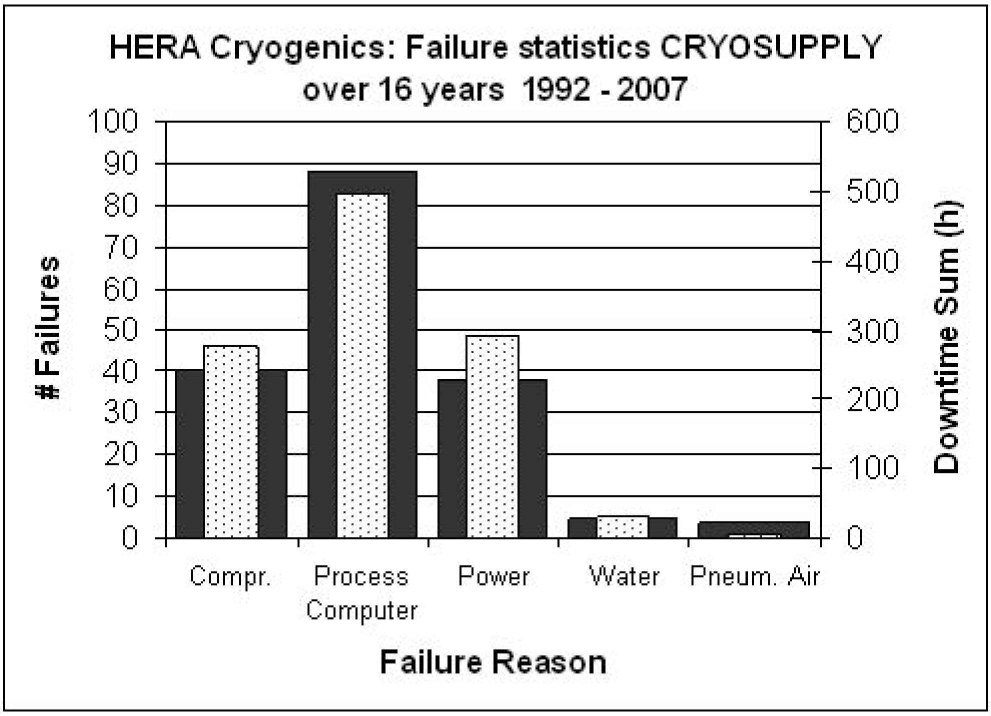

Fig. 3 Failure statistic of the refrigeration plant and its infrastructure. The filled bars display the number of failures and the dotted ones present the added downtime with respect to the respective category.

As can be seen in the diagram the main failure reason of the plant is related to the availability of the corresponding process computer or rather of the process control system of the plant, its infrastructure and the HERA accelerator. In the first few years mainly defect power supply units, multiplexer and programming mistakes caused a plants' downtime. Later on the SEDAC I/O in the accelerator ring, mainly the SEDAC controller and the power supplies for SEDAC crates, partly due to radiation damage, have been responsible for a discontinuation of the cryogenic supply. Though the controls caused a large relative fraction of downtime, it should be stated that the involved system ran very stable through the operation time of HERA and that the absolute downtime given by control failures was very low. Secondly compressor problems have to be mentioned to cause a technical breakdown of the plant. On average three times a year a compressor-station, consisting of four compressors respectively (three low pressure and one high pressure stage), caused an emergency stop of the refrigeration plant. Operating errors, oil-leaks and electromagnetic problems in terms of loose connections can be mentioned as reasons for compressor malfunctions. Besides the frequency-converters, which have been integrated in 2004 caused a small part of the downtime related to compressor problems. Tertiary power outages lead to technical breakdowns of the plant. Indeed the number of failures caused by power outages is less than due to compressor problems but the induced added downtime is even higher. In average 2.5 power outages per year, mostly short breaks due to thunderstorms, cause a long term break down of the plant.

Additionally to the failure reasons mentioned so far also cooling water and pneumatic air failures cause discontinuation of the cryogenic supply, but with an average of one failure per three years it is negligible in contrast to process computer, compressor and power failures. To sum up, power and compressor failures, leading to a technical breakdown of the plant, are approximately equal in quantity and half the amount of process computer failures. Most of the downtime due to process computer failures is caused by problems with process control system in terms of missing redundancy and the obsolete SEDAC I/O-System.

As far as our experience goes a plant-availability of 99 % is possible if periodical maintenance as well as the exchange of critical components (O-ring sealings, power supplies, emergency-power supplies, PLC's, etc) is carried out. Besides, up-grades of the plant have been made to improve its performance and availability as well as operational costs. After the suction pressure of the Joule Thomson compressors had to be lowered to 0.6 bar to achieve an operation temperature of 4.0 K at the superconducting magnets and the FLASH linac had to be supplied in addition the maximum flow rate of the low pressure stage compressors has been reached. As a result, the third, redundant compressor and coldbox group had to be used for the supply of the FLASH linac. The third coldbox was run at its minimum capacity level and correspondingly in a rather inefficient way which in addition meant a loss of redundant components for the HERA cryogenic supply. To compensate for the lower suction pressure the rotational speed of the low pressure stage compressors had to be increased by 20 % (60Hz instead of 50Hz operation) by using frequency converters. In the year 2002 two compressors have been equipped with frequency converters. Besides the control of the compressor volumetric flow was more efficient henceforth. Due to our good experiences with this modification another 5 low pressure compressors have been equipped with frequency converters. The costs of equipment and assembly could be amortized within two years because the power consumption was lowered by 18 % compared to the sliding valve regulation. Additionally the full redundancy was won back. The three remaining low pressure compressors of the turbine circuit (including redundancy) which still had been run by sliding valve regulation were upgraded with frequency converters in 2007. A short period of amortization is expected here, too. For detailed information see [4]. A further activity to enhance the operability of the refrigeration plant is the change from the proprietary process control system EMCON D/3 to the open source system EPICS. This conversion was started in 2002 for several plant components and will be enlarged to the whole plant soon. This modernisation of the process control system does not only enhance the flexibility in operating the refrigeration plant but also reduce the operating costs in terms of maintenance and upgrading.

SUMMERY AND OUTLOOK

The demands of the HERA refrigerant plant were and are very high. Only due to the refrigeration plant's great reliability physicists at DESY were able to research on superconducting accelerators on such a high level in previous years and will be able to do so in future times. In the course of the years changes were made regarding hardware as well as software to remain always on the state of the technology and to ensure a high availability of the plant. In addition overcapacity or rather redundancy was essential to reduce the refrigeration plant's downtime to a minimum. Related to high availability the experience has shown that redundancy must be given and special attention must be paid to the helium compressors and the electricity supply, in particular to the process computers and the process control system. Besides it is worth mentioning that despite being on the state of the technology, apparently secondary or rather trivial problems can cause a technical breakdown of a refrigeration plant.

In future one of the three refrigerating units will be used for the cryogenic supply of the FLASH linac, the cryomodule test bench, the magnet test hall and the accelerator test facility. The remaining two units will be modified and upgraded for the cryogenic operation of the future XFEL linac [5,6].

REFERENCES

1. Barton jr., H. R., Clausen, M.; Horlitz, G., Lierl, H., „Central Refrigeration System for the Superconducting HERA Proton Magnet Ring“, Proceedings ICFA Workshop on Superconducting Magnets and Cryogenics, Brookhaven Nat. Lab., Upton, N. Y., May 12-16, 1986.

2. Barton jr., H. R., et al, “The refrigeration System for the Superconducting Proton Rind of the Electron Proton Collider HERA”, Adv. In Cryog. Eng., Plenum Press, N. Y., 1986, 31, 634

3. Clausen, M., Herzog, H., Horlitz, G. Knopf, U., Lange, R., Lierl, H., „Cryogenic test and Operation of the Superconducting Magnet System in the HERA Proton Storage Ring“, Adv. In Cryog. Eng., Plenum Press, New York, 1992, Vol. 37A, p. 653.

4. Herzog, H., Klos, R., Molnar, S., Petersen, B., Rother, J., Schroth, W., Stephan, M., „Upgrade of the Compressor System of the HERA Cryogenic Plant by the use of Frequency Converter Power Supplies“, International Cryogenic Engineering Conference – ICEC 2, Vol 1.

5. Linde-Kryotechnik AG, „Machbarkeit der Verwendung der HERA Kälteanlagen beim Europäischen XFEL-Projekt“, internal report DESY/Linde Kryotechnik AG, 2006

6. Bozhko, Y., Lierl, H., Petersen, B., Zolotov, A., „Requirements for the Cryogenic Supply of the European XFEL Project at DESY“, CP823, Advances in Cryogenic Engineering: Transaction of the Cryogenic Engineering Conference – CEC, Vol 51.