THE CRYOGENIC OPERATION OF THE SUPERCONDUCTING MAGNET SYSTEM IN THE HERA PROTON STORAGE RING: COOL DOWN, STEADY STATE OPERATION, QUENCH RECOVERY PROCESSES

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Abstract:

The 6.4 km long superconducting proton storage ring of HERA was completed in 1990 [1]. In October the first halfring was cooled, in December the second one. Steady state operation could be established after about 200 hours. We report on the cryogenic operation of the system during cooldown and steady state operation and give values for thermal losses. One octant was excited up to values exceeding the design current. Some results of quench tests in this octant are presented.

I. INTRODUCTION

Design and layout of the superconducting HERA proton magnet ring have been published several times [2]: In a Ringtunnel of 6366 m circumference 422 dipoles and 224 quadrupoles including correction elements have been installed. The operating temperature of the magnets is maintained by means of supercritical helium from a central refrigeration station. It passes through the magnets at a temperature of 4.4 K and at a pressure of 2.5 bar, and it is recooled in the magnets by thermal contact with returning two phase helium at 1.1 bar.

Cooldown was performed seperately for each halfring . Results of cooldown and steady state operation measurements are given below.

First quench tests have been executed with one octant only.

II. CRYOGENIC SYSTEM

The cryogenic system is shown schematically in Fig. 1. The total cooling power is produced by means of 3 identical groups of cold boxes and compressors. Technical details may be found in [2] . Each cold box is sufficient to supply one half ring. In normal operation the third box remains redundantly in stand by.

Tab. 1 gives the most important data of the refrigerators.

Tab. 1 Main Data of Refrigerator Units

Refrigeration 4.3 K	6775 W
Refrigeration 40/80 K	20000 W
Current lead flow	20.5×10^{-3} kg/s
total mass flow	0.871 kg/s
Primary power	2845 kW
Specif. power consumption	281 W (300 K)/W (4.3 K)

The ring is subdivided into 8 identical sections (octants). Each octant can be operated independently by means of end boxes and middle boxes being arranged as shown in Fig. 1. A cryogenic four tube transferline supplies and returns helium at about 4,5 K for the superconducting magnet coils and at 40/80 K for the heat shields.

In addition there are gas tanks (12) and dewars for liquid helium (9) and liquid N2 (11) as well as purification units (5;10). A process control computer enables the operation, the control and data storage.

III. COOL DOWN

The cooling of each octant occurs in 3 phases:

1) He-gas is precooled to 82 K by means of liquid nitrogen via special heat exchangers in the cold boxes. The gas enters the octant from both ends at flow rates of approx. 100 g/s and leaves it in the middle (Fig. 2). Two cold fronts move into the octant as can be seen in the same figure. It is important not to exceed a maximum temperature/time gradient of about 20 K/h in order to avoid dangerous mechanical stresses in the magnets.

The cool down time from 293 K to 82 K was about 70 h for one half ring (the 4 octants have been cooled in parallel). The limitation was the liquid nitrogen supply which was maintained by trucks. An amount of about 450 000 l in this phase is required for one halfring.

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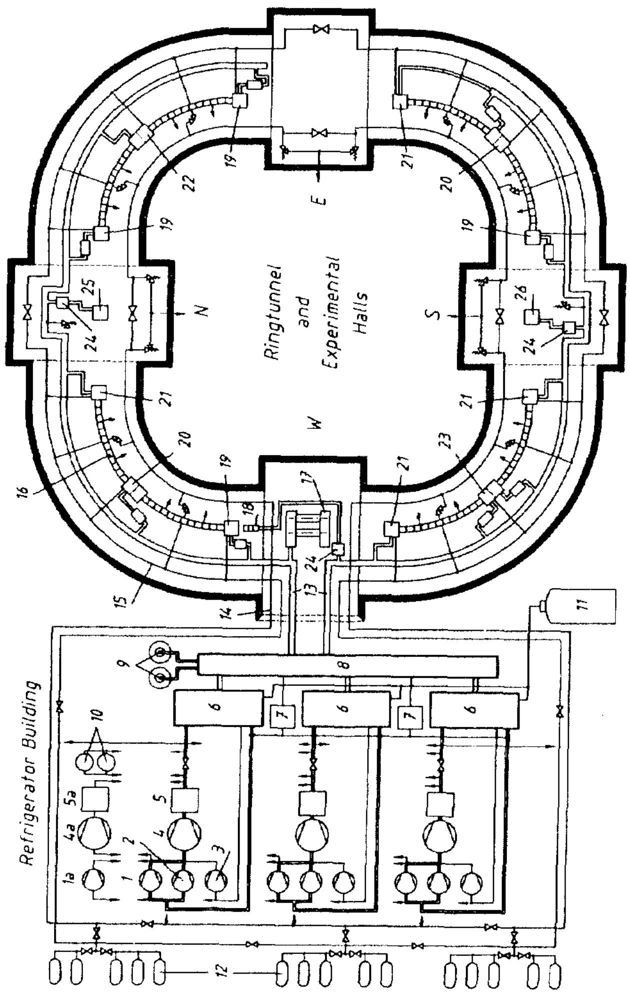

Fig. 1 HERA Proton Ring Cryogenics

compressors, first stage (1;2;3;1a), second stage (4;4a), gas purification (5;5a), cold boxes (6), return gas heater (7), distribution valve box (8), LHe tanks (2 x 10 m^3) (9), cryogenic purifiers (10), LN2 tank (150 m^3) (11), warm gas storage tanks (15 x 267 m^3, 20 bar)(12), 4 channel cryogenic transferline (13), quench gas collection line (14), 300 K/20 bar He supply line (15), superconducting magnet strings (16), 2 reference magnets (17),8 superconducting e⁻ ring HF cavaties (18), precooler endboxes EC (19), middle box MJC (20), Joule-Thomsen valve endbox EJ (21), middle box MJJ (22), middle box MCC (23) detector supply box HV (24), detectors H1 (25), ZEUS (26)

2) Below 80 K the incoming gas is cooled by the turbines, supported by LN2 in order to get the maximum cooling capacity. The gas flow enters the octant now at one end and leaves it at the other end.
A period of about 80 h was required to reduce the temperatures to about 10 K (fig. 3).
3.) Below 10 K the He at the end of the octant is expanded from 2.5 bar to 1.2 bar, partially liquefied and the two phase mixture is returned through the magnets, thus establishing the final temperature within 48 hours (fig. 3).

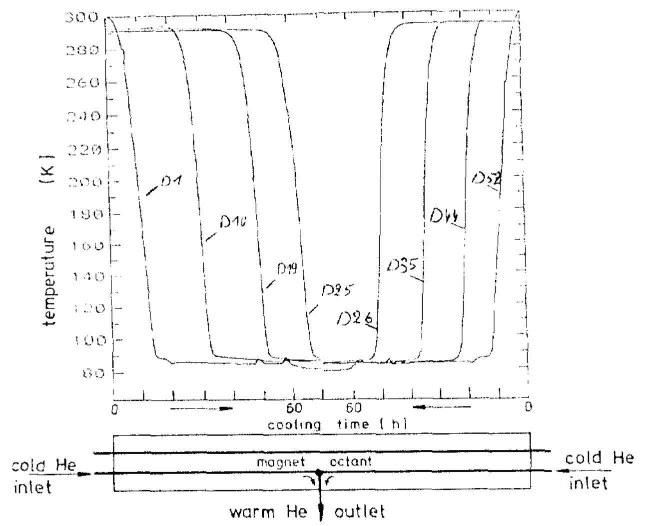

Fig. 2 Octant cool down from two ends (phase 1)

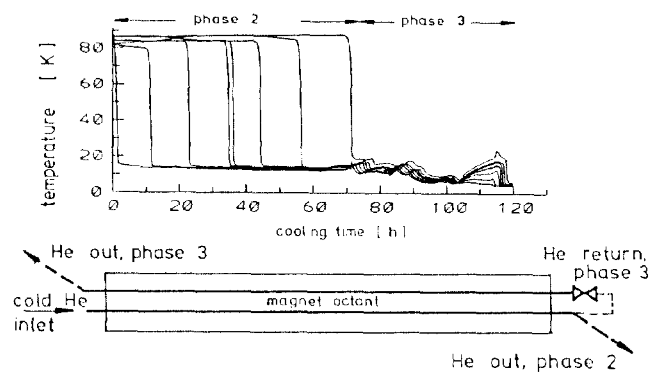

Fig. 3 Octant cool down (phase 2+3)

The total cooldown time for one halfring was 198 h = 8.25 days. This value will be improved in the future by more experience.

The total liquid nitrogen consumption for one halfring amounts to approx. 500 m^3, including cooling for magnets, heat shields and cryogenic purifiers.

IV. STEADY STATE OPERATION

Stability and control performance of one individual octant have been investigated and published earlier[3]. The parallel operation of 8 identical octants did not add any problems.

After having established stationary operation conditions the heat loads in different sections of the system have been measured. The results are listed in Tab. 2.

Tab. 2 Heat Loads of the System (preliminary)

Section	North	South	
4,5 K transferline	508 ± 100	413 ± 100	W
Σ octants	1999 ± 50	2174 ± 50	W
total	2507 ± 120	2587 ± 120	W
average transferline	0.16 ± 0.03	0.13 ± 0.03	W/m
octants	500 ± 50	544 ± 50	W/oct.
40/80 K transferline	2450 ± 500	2700 ± 500	W
section OR		800 ± 100	W
Σ octants	11250 ± 200	11300 ± 200	W
total	13700 ± 500	14800 ± 500	W
average transferline	0.774 ± 0.2	1.095 ± 0.2	W/m
octants	2813 ± 50	2825 ± 50	W/oct.

They are in good agreement with the design values. There remains sufficient cooling power in excess for the supply of other equipment as superconducting detector solenoids, HF-cavaties, (for the electron ring) and reference dipoles.

V. QUENCH BEHAVIOUR

In octant WL single magnets have been quenched at different values of current by firing heaters in the windings.

At 5000 A a number of 18 dipoles was quenched.The pressure in the magnets did not exceed 6,7 bar and the helium was discharged into the buffer tanks (12, fig. 1) and then reliquefied.

A maximum quench of all dipoles at a current of 6000 A (far above the operating current of about 5000 A) raised the pressure to more than 8 bar (the limit of the recorder during this unforeseen quench). The pressure decayed through the safety valves within a few seconds and the helium was completely collected in the buffertanks. Recooling is demonstrated in Fig. 4 which shows the temperatures of the last magnets of the octant.

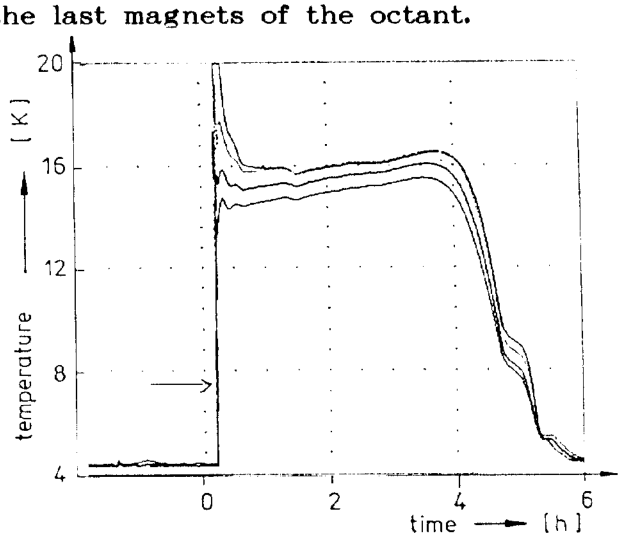

Fig. 4 Octant Recooling after Quench (Last Magnets)

The recovery time of approx. 6 hours is not optimized yet but the test proves that even total quenches of all magnets at highest currents can be handled by the cryogenic system: no gas is lost, the pressure remains within predicted limits and the recooling process can start immediately after the quench.

VI. LONG TIME OPERATION EXPERIENCE

The refrigeration system was completed in Dec. 1988. Operation started immediately for supplying a test facility which measured all magnets before they were installed in the tunnel. In the first half of 1990 one octant was operated for about 4 months, the commitment of the whole ring started in October 1990. Total running times of compressors and coldboxes are of the order of 12000 h for each group. The failure rate of all components is still so low that a statistic is not yet possible.

VII. SUMMARY

The HERA refrigeration system has been completed. All performance tests have satisfying results. Reliability has been excellent over running times which vary, depending on the date of completion from several months to 2.5 years. All control and safety devices work well. Heat loads and refrigeration power are as designed. From the cryogenic point of view the ring is ready for operation.

REFERENCES

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