ELBE Accelerator: First Year of Cryogenic Operation

Haberstroh Ch.

Lehrstuhl für Kälte- und Kryotechnik, TU Dresden, 01062 Dresden, Germany

At the research center Rossendorf near Dresden the ELBE accelerator (Electron Linac of high Brilliance and low Emittance) was put into operation recently. A quasi-continuous electron beam (cw) with a maximum energy of 12 ... 40 MeV can be produced for application in basic nuclear research and for driving a free-electron laser [1]. Acceleration is actually performed by using two 9-cell superconducting cavities (TESLA type) contained in a single first cryostat.

The helium plant to maintain the working temperature of about 1.8 K was planned in cooperation with the TU Dresden. It has a cooling capacity of more than 200 W at 1.8 K to cover the high dynamic heat load connected with the cw regime. A special feature is the use of a two stage cold compression, handling a nominal flow-rate of 10 g/s.

The first accelerator cryostat had been in operation since May 2001, and several month periods of uninterrupted He II cooling had been achieved from the very beginning.

This paper reports on operating experience of the cryogenic system and on detail problems which had to be faced so far.

BASIC DESIGN OF THE HELIUM PLANT

The helium plant was specified for 200 W at 1.8 K plus 200 W at 80 K (the later being only partly used now for other reasons). It represents herewith the forth in size all over Germany. The basic process is shown in Figure 1.

The plant may be understood as a 4 K machine based on the usual Modified Claude process, with an additional 1.8 K extension. The 4 K part comprises three expansion turbines. The cycle compressor is split into two units with 266 kW and 60 kW electrical input power respectively, allowing a flexible adaptation to different refrigeration modes. In case of need the refrigeration capacity can even be upgraded by retrofitting a stronger compressor unit. In addition liquid nitrogen precooling is possible (not applied so far).

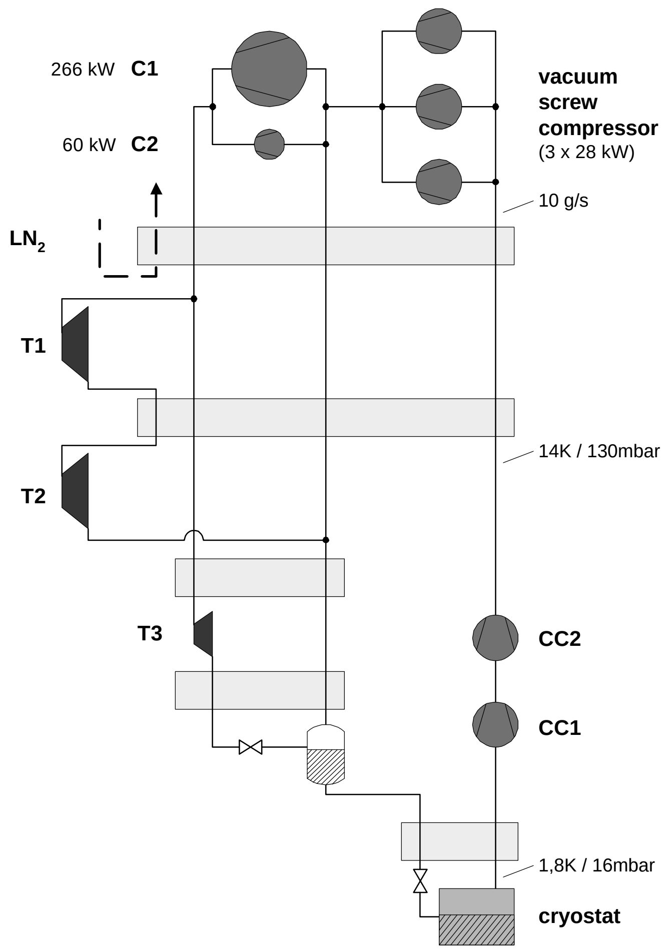

Figure 1 Simplified flow scheme ELBE helium plant

The 1.8 K extension consists of a remote distribution cold box inside the accelerator cave, containing the subcooling heat exchanger and cryogenic valves. Helium is expanded into the cavity cryostat, nominally working at 1.8 K or 16 mbar respectively. Recompression is done both by volumetric and dynamic machinery: at the design point (10 g/s) the 16 mbar return gas is compressed to approx. 130 mbar by means of two Cold Compressors in series, allowing to reduce the following heat exchangers to feasible dimensions. Final recompression is done by warm vacuum screw compressors (3 in parallel for capacity reasons).

Inside the cryostat a pressure fluctuation of less than ± 0.1 mbar can be tolerated in order not to effect the RF resonance conditions of the cavities. Pressure adjustment is done exclusively by control of the rotational speed of the cold compressors.

TIME SCHEDULE

In December 1996 the plant was ordered at Linde Kryotechnik, Pfungen, as general supplier. After appreciable delay caused by hold-up in the building works, delivery and installation could be started in 7/98. Commissioning work started in 4/99, with acceptance in 11/99. Directly following the installation, a liquefier extension was accomplished, induced by additional liquid helium demand meanwhile emerged.

January 2001 the first accelerator cryostat was in place, in spring 2001 the first test campaign could be started. Systematic Linac operation took place in the period from 5/01 until 12/01. It was followed by a long shutdown period (1/01 – 8/01), conditional upon comprehensive building works and beam line conversion. This period was used for helium liquefaction (stand-alone liquefier mode) to supply other experiments. Furthermore routine service and revision work at the helium plant were performed.

OPERATIONAL EXPERIENCE

Acceptance tests

For acceptance of the complex helium plant, a catalogue of single tests had been defined. These were essentially passed end of 1999. Due to the delay of the cryostat initiation, the tests were performed by means of the electrical heater inside the subcooling cold box, with blanks at both ports towards cryostat.

In full load mode a capacity exceeding 203 W at 1.8 K could be demonstrated. Furthermore part load, standby mode, automatic cool down / warm up were tested, as well as e.g. shutdown behavior (simulated by utility failure or intentional maloperation), leak tightness, purifier operation, function of recovery system or noise level. No appreciable deficiency had to be stated.

Liquefier mode

The nominal capacity in “stand-alone” liquefier mode (2.86 g/s corresponding to 82 l/h, minus 5 ... 10 % for purifier operation) is reached approximately.

As a separate task liquefaction plus cryostat in 1.8 K standby mode (static heat load, ~ 20 W) was defined. Here theoretically 1.6 g/s corresponding to 46 l/h (minus 5 ... 10 % for purifier operation) can be withdrawn. In practice the liquefaction rate should be limited here to about 30 l/h in order to ensure an abundant safety margin to machine parameter limits.

Linac operation

It should be pointed out that there emerged a significant discrepancy between the design values originally demanded from the refrigeration system and the operation conditions as they effectively were found during the first operational period:

- exclusively 9 % to 25 % part load instead of full load operation
- the originally foreseen electric heater inside the cryostat to compensate missing cavity heat load was not procured
- instead of 16 mbar design pressure Linac operation was done at up to 30 mbar, which turned out to be advantageous in some other respects

- a breakdown of the cryostat vacuum was classified originally as quite unlikely; nevertheless rupture discs and safety valves were procured in the 16 mbar return system to avoid possible machine damage; in fact not less than three fatal occurrences of complete vacuum collapse happened within a few month only.

Despite all these handicaps a persistent He II regime could be continuously sustained from the very beginning. The plant can be characterized by a forgiving behavior. Right from the start a widely uninterrupted refrigeration supply could be achieved. Helpful here is the fact, that with no RF power applied (~ 20 W static heat load solely) the vacuum screws alone, without Cold Compressor operation, can maintain a helium vapor pressure of about 25 mbar.

<u>Incidents</u>
Major incidents occurred during up to date 6000 to 9000 hours of operation (dependent on the individual working time of the single components) are listed in Table 1.

Table 1 Major incidents at the helium plant from initiation until mid of 2002

Failure	**Consequences**
utility cut (cooling water, instrument air, power supply)	no damage; restart without problems
failure of vacuum screw compressor	preventive refurbishment of all three units
stucked expansion turbine	particle removed
repeatedly drop out of digital ARCA valve positioner inside cave (radiation damage?)	replaced; sensitive electronics remotely placed outside cave for prevention
breakdown of isolation / beam line vacuum inside the cryostat	helium plant untouched; preventively additional interlock to protect helium plant foreseen
accumulation of water contamination inside helium system (originating from different average events, leakage etc.)	purging

So far no dramatic down times of the helium plant has to be stated. Nearly no cost of repair incurred for the owner within the whole time (some of the measures mentioned above were still covered by warranty).

"1 Hz " – PHENOMENON

A quite unexpected effect was observed soon after beginning of the Linac operation. When applying a moderate RF load to the cavities, a pressure oscillation emerged in the whole 16 mbar system. Discrete frequencies were found, typically around 1.1 Hz, sometimes down to 0.3 ... 0.14 Hz (depending on operation parameters). At the same time a liquid level fluctuation (swashing) inside the two-phase tube was excited, finally mounting in a dislocation of liquid inventory towards the distribution cold box via 16 mbar return line. The amplitude of the pressure oscillation hereby was in the order of ± 0.3 .... ±1 mbar, thus preventing further RF induction by detuning the cavities. This effect essentially limited the achievable acceleration gradient over the whole first operation period.

A large number of possible reasons had been checked and ruled out: Taconis oscillation, resonance within the helium plant, feedback of pressure controller or RF controllers, He II effects etc. A capillary bypass to the closed cool down line (forming a gas spring) gave some slight improvements. By chance it was found that the oscillations were partly repressed while working at higher pressure levels (e.g. 24 ... 30 mbar, still well below the lambda line). Therefore a number of Linac experiments were performed at elevated helium pressure from that time.

It could be calculated that the Eigenfrequency of the gas column inside the 16 mbar return line (total length from cryostat to the Cold Compressors approx. 31.5 m with approx. 0.2 m^3 geometric volume) is in the order of 1 Hz as well. Finally evidence for stall regime of the Cold Compressors could be found, obviously due to the extreme part load mass flow conditions [3]. This explanation had first been excluded because of oscillation occurrence even well inside the “allowed” regions of the turbocompressor performance map (inside the stall limit), with a software-based stall prevention procured as well. The surprising low frequency seems plausible in view of the large resonance volumes both at suction and exhaust lines of the turbo compressors. It could be demonstrated moreover that the oscillations vanished when the mass flow was brought close to the design point by means of additional cold gas injection at the suction side of the cold compressors.

For relief the cold compressors were checked completely during the routine service for damage possibly supporting the stall regime (no severe damage found). The existing acceleration cryostat (Cryomodule I) shows apparent deficiencies (missing electric heater, improper phase separation). Both will be overcome in an improved version, operated by end of 2002 instead of Cryomodule I.

CONCLUSION

A low frequency oscillation at the 16 mbar pressure level, dominating the first Linac operation period and effectively limiting the applicable acceleration gradient, was explained by a stall regime of the cold turbo compressors, induced by unfavorable working conditions and distinct deficiencies of the cavity cryostat. The effect will be overcome by improved features of the next cryostat version.

Despite that, the helium plant showed stable and forgiving behavior. Both process concept and hardware components proved themselves, even under aggravated working conditions. No replacement or modification worth mentioning was necessary within the first years of operation.

ACKNOWLEDGEMENT

Particularly in the beginning of the Linac operation a lot of consultative contacts took place. The author would like to express his sincere gratitude especially to K. Löhlein, Linde, for intensive and patient technical assistence of the Rossendorf operating crew, furthermore to numerous colleagues from DESY, to K. Petersen, FNAL, P. Seyfert and B. Rousset, CEA Grenoble, A. Hofmann, FZ Karlsruhe and W. Hees, CERN, for helpful discussion and support.

REFERENCES

1. www.fz-rossendorf.de → ELBE
2. Haberstroh, Ch. and Quack H., Cryogenic System for the ELBE Linac in Dresden, Proc. of the Symposium on Cryogenic Systems for Large Scale Superconducting Applications, Toki, Japan, ed. by T. Mito (1996), 94 - 97
3. Bezaguet A., Lebrun Ph. and Tavian L., Performance Assessment of Industrial Prototype Helium Compressors for the Large Hadron Collider, proc. ICEC 17 (1998), 145 - 148