THE LIQUID HELIUM SYSTEM OF ATLAS

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Abstract

Starting in 1978 with one small refrigerator and distribution line, the LHe system of ATLAS has gradually grown into a complex network, as required by several enlargements of the superconducting linac. The cryogenic system now comprises 3 refrigerators, 11 helium compressors, ~340 ft. of coaxial LHe transfer line, 3 1000-ℓ dewars, and ~76 LHe valves that deliver steady-state flowing LHe to 16 beam-line cryostats. In normal operation, the 3 refrigerators are linked so as to provide cooling where needed. LHe heat exchangers in distribution lines play an important role. This paper discusses design features of the system, including the logic of the controls that permit the coupled refrigerators to operate stably in the presence of large and sudden changes in heat load.

Introduction

ATLAS [1] is a superconducting heavy-ion linear accelerator that has grown steadily in size, complexity, and research capability since the first part of it went into operation in 1978. By now it has logged 35,000 hours of operation with beam on target for research with heavy-ion projectiles.

The steady expansion in the size of ATLAS, brought about by its successful performance at each stage, required a corresponding expansion in the cryogenic system. This expansion had to be achieved at minimum cost and with little loss of running time for the existing accelerator system. These requirements were met by attaching new subsystems on to the original installation, with small design improvements where desirable. This process has produced a system that may be more complex than is optimal but, on the other hand, its great flexibility and redundancy is valuable.

The original prototype linac consisted of one small, and two larger, cryostats which contained niobium split-ring resonators and superconducting focussing magnets cooled by forced-flow circulation of liquid helium from a CTI Model-1400 helium refrigerator [2]. In 1980 a CTI Model-2800 turbo-expander refrigerator was installed [3] in parallel to cool an additional cryostat and provide capacity for anticipated future expansions. By 1985 the linac was almost doubled in size, and to keep pace with the increased load the original Model-1400 was replaced [4] by a Model-1630, and additional screw compressors were added for it and the 2800, bringing the total rated capacity to about 480 W. In 1987 the original Model-1400 was added to the system again in order to increase capacity and provide for early testing of the latest major addition to ATLAS - the positive-ion injector [5-8].

At the present time we are replacing the Model-1400 with a second Model 2800 turbo-expander machine and two more screw compressors to provide capacity for the three large cryostats that are anticipated for the positive-ion injector. With these additions, the total installed cooling capacity should be in excess of 700 W at 4.6K.

Basic Flow Scheme

Each addition to the system over the past decade has been an extension of the original basic series circuit (see Fig. 1) described previously [2]. On the main outgoing line there is a pair of tees and valves with which to direct flow to and from each cryostat. The tees are separated by by-pass valves on the main line. The by-pass valves can be fully closed to force the entire flow through the cryostats, or may be throttled to provide to the cryostat only as much flow as required, by-passing the remainder downstream. With this arrangement any cryostat may be removed from the system without affecting operation of the others.

An essential feature of the system is the series of condensing heat exchangers located in each of the three dewars, and in five of the valve boxes. By means of these heat exchangers the gas fraction of the outgoing higher-pressure, warmer, two-phase flow can be condensed by heat exchange with the lower-pressure, colder, returning two-phase flow. The tube-side coils of these heat exchangers are immersed in the pool-boiling shell-side reserviors that are kept full by overflow from the previous heat exchangers. The dewars act as pool-boiling baths for their coils, as surge tanks, as phase separators for the gas returning to the refrigerator, and as control elements in which levels or pressures can be maintained.

As each addition has been made over the past eleven years, improvements based on experience have been incorporated. Among these are (a) better cooldown flow arrangements for each cryostat, (b) larger liquid- helium valves and piping to minimize pressure drop, (c) separating the valve box/distribution line insulating vacuum into four separate zones, and most significantly, (d) adding a number of closed loops for control of valves and dewar heaters for maintaining desired pressures or levels in the dewars over long periods of time.

Control System

The controls of the liquid-helium system of ATLAS must be able to adjust easily to large and sudden changes in heat load that may occur frequently because of changes in the operating conditions of the linac. Also, it must be able to provide cooling to parts of the linac while other parts are out of operation. Finally, the linac must be kept cold continuously for long periods of time, preferably years. The logic of the control system used to achieve these objectives is shown schematically by Fig. 2 and, in more detail, in Fig. 1. First note that refrigerators 2800East and 1630 are tightly coupled in their liquid-helium outputs and in their cold-gas returns. The pressure in one of the coupled 1000-ℓ dewars (J or K) is controlled by means of a heater to ensure that the suction pressures of the compressors feeding the refrigerators are positive. Typically, <5% of the refrigeration capacity is dissipated in this way.

The tight coupling of the refrigerators automatically distributes the heat and gas loads efficiently to the two units, and the performance of

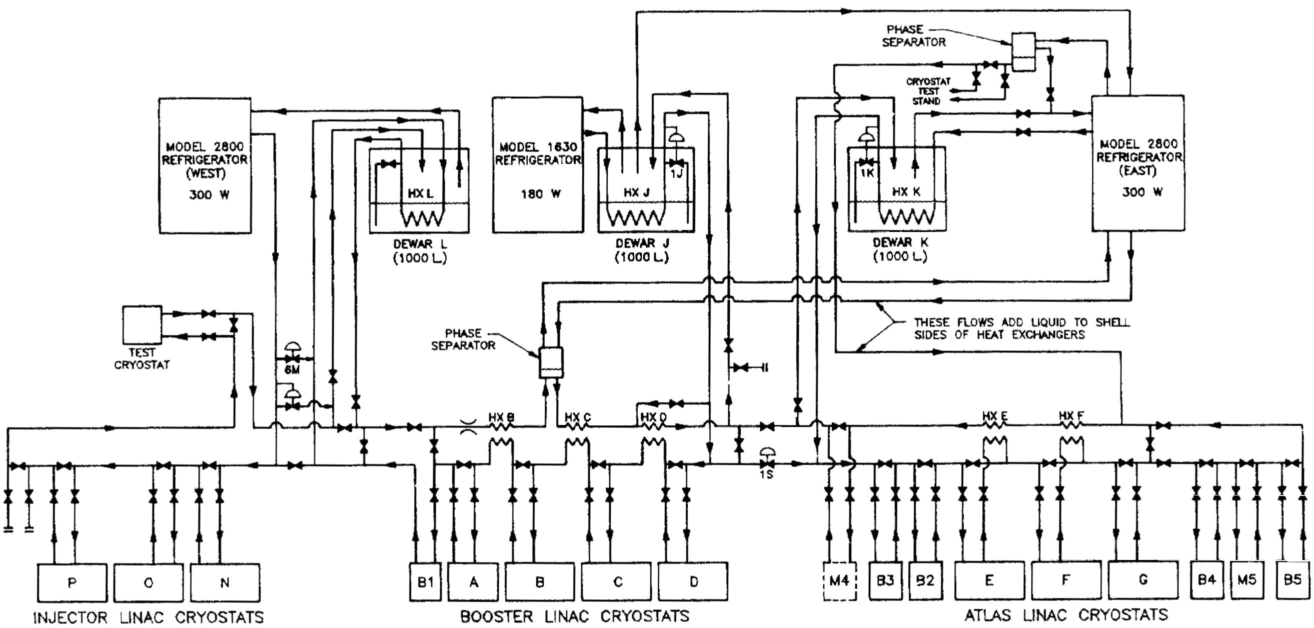

Fig. 1 Detailed schematic of the liquid-helium system of ATLAS. Warm-gas recovery lines are not shown.

one refrigerator is not changed much when the operating conditions of the other are changed. That is, the parallel linkage does not cause operational instability. On the other hand, the warm-gas piping from the compressors of the two refrigerators is not normally connected because this does cause instability.

Pneumatic control valves are used for two different kinds of functions. One is to limit the pressure of the high-pressure LHe flow delivered to the linacs. The limiting pressure is normally set at 15 psig, which results in a substantial amount of sub-cooling of the LHe that enters the first cryostat of each linac. The pressure is controlled by means of proportional bypass valves (V-1J and V-1K, Fig. 1) that dump their output flow into dewars J and K, respectively. This pressure-control feature has contributed greatly to reliable operation because it prevents accidental pressure excursions that cause troubles by opening relief valves.

The second function of a control valve is to regulate the division of LHe between dewars J and K since, without active control, liquid tends to wander from one dewar to the other, depending on operating conditions. This problem has been eliminated by controlling the liquid level in J and letting the level in K vary. Two mechanisms are used for this control: (1) the opening of valve V-1S in the LHe line between J and K (see Figs. 1 and 2) is controlled by the liquid level in J and (2) simultaneously, the same control selects which dewar heater is actuated for dewar-pressure regulation, thus reinforcing the action of valve V-1S.

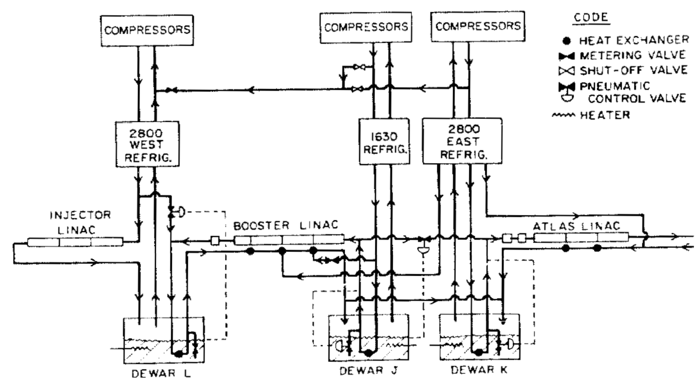

Fig. 2. Schematic of basic interconnections and control features of the ATLAS cryogenic system under normal operating conditions.

The new refrigerator 2800West is needed principally to cool a new injector linac [7], but it was also desirable to have it provide some additional cooling for the existing linacs, which are cooled mainly by the 1630 and 2800East. The problem was how to do this at minimum cost under the constraints imposed by the design of the existing LHe distribution line, building space, and linac-operating requirements. This problem has been solved by breaking into the existing LHe line just downstream from the superconducting buncher B_1 (Fig. 1), where the flowing helium contains considerable gas. This flow is now passed through a heat exchanger in the new dewar L that is fed by refrigerator 2800West. In this way, the two-phase helium stream is converted to sub-cooled liquid, and about 40 W of heat from the original linac can be transferred to the new refrigerator without any interchange of fluid between the two sytems. The only limitation on this arrangement is that the pressure in dewar L must be lower than the pressure of the helium being cooled.

A second, less efficient, way to transfer some of the heat load from the original linac to the new refrigerator is to direct some of the high-pressure warm gas from the compressors of either the 1630 or the 2800East to the suction side of the compressors that feed the 2800West. This gas is liquified by the 2800West and then, by means of a valve controlled by the liquid level in dewar L, the excess liquid is returned to the original linac, where it provides some additional cooling capacity. This technique is surprisingly effective, but it is not often used because of inadequate compressor capacity. Note that any net interchange of helium between the new and old systems results in a change in the liquid level of dewar K, since the level of J is controlled.

Operational Flexibility

Upon completion of the current additions there will be three refrigerators, seven 100 kW screw compressors, and four 25-kW reciprocating compressors installed. Having this number of individual components, which can be interconnected on both the LHe and warm gas sides of the system, allows much greater flexibility in matching refrigerating capacity to varying heat loads than would one large refrigerator and compressor. It also allows for continued operation of the linac at reduced energy levels in case of refrigerator or compressor maintenance or failures. Most important, it enables us to keep the linac cold for long periods of time in spite of failures of refrigeration equipment, thus minimizing the loss of accelerator running time because of time spent cooling cryostats and conditioning superconducting accelerating structures.

An example of the immense versatility of our cryogenic system is illustrated in Fig. 3, which shows the multiplicity of activities carried out simultaneously on a recent day. (1) The existing ATLAS accelerator was being operated to provide an ion beam for research. (2) A warm buncher cryostat B_4 was being cooled, giving a load from warm-gas return to the refrigerators. (3) A test cryostat being fed by a dewar was also returning warm gas. (4) A very large new cryostat [7] associated with the new positive-ion injector was being cooled to LHe temperature for the first time, giving loads from (a) cold-helium return to the 1400 (then installed instead of the 2800West), (b) warm-helium return of part of the cold-fluid output of the 1400, and (c) warm-helium from liquid being transferred from a dewar into the new cryostat. The warm gas from the new cryostat was directed both to the 1400 and the 2800East. Consequently, some of the liquid from dewar L was sent as warm gas to the 2800East, and it was necessary to replace this liquid by liquid flow into L from the original LHe line. Since the refrigeration system did not have enough cooling capacity to carry out all of these functions simultaneously, the capacity was augmented by vaporizing LHe from the storage dewars and using refrigerator compressors to transfer the excess gas to a storage tank. Fortunately, operation at this level of complexity is atypical.

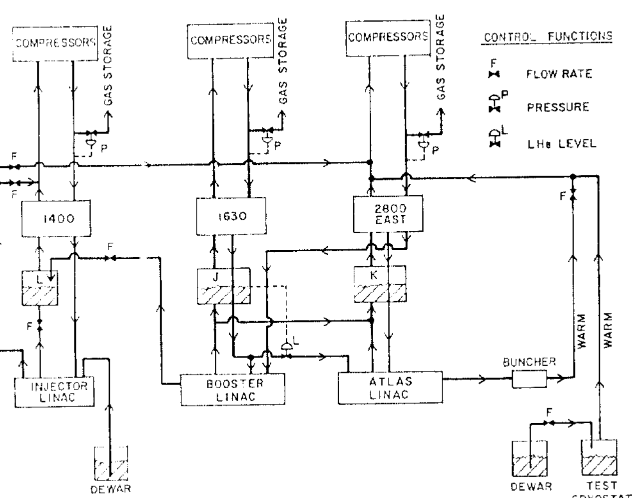

Fig. 3 Use of the ATLAS cryogenic system to perform several tasks simultaneously.

Acknowledgment

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