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DESIGN OF THE COOLANT SYSTEM FOR THE LARGE COIL TEST FACILITY PULSE COILS*

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Summary

The pulse coils will be a part of the Large Coil Test Facility in Oak Ridge, Tennessee, which is designed to test six large tokamak-type superconducting coils. The pulse coil set consists of two resistive coaxial solenoid coils, mounted so that their magnetic axis is perpendicular to the toroidal field lines of the test coil. The pulse coils provide transient vertical fields at test coil locations to simulate the pulsed vertical fields present in tokamak devices. The pulse coils are designed to be pulsed for 30 s every 150 s, which results in a Joule heating of 116 kW per coil. In order to provide this capability, the pulse coil coolant system is required to deliver 6.3 L/s (100 gpm) of subcooled liquid nitrogen at 10-atm absolute pressure. The coolant system can also cool down each pulse coil from room temperature to liquid nitrogen temperature. This paper provides details of the pumping and heat exchange equipment designed for the coolant system and of the associated instrumentation and controls.

Introduction

The pulse coil coolant system (PCCS) was designed to meet the following criteria:

1. Provide subcooled liquid nitrogen (LN_2) to each of two resistive pulse coils, located inside the Large Coil Test Facility (LCTF) vacuum vessel, at a flow rate sufficient to dissipate 116 kW of heat per coil for each 30-s pulse.
2. Provide a method of cooling the pulse coils from room temperature to 80 K with a maximum temperature gradient of 40 K (75°F).
3. Use to the greatest extent possible the existing LN_2 system, which provides cryogen to the vacuum vessel cold wall and other parts of the LCTF.

The existing LN_2 system is pressure-fed, open-loop system, supplied by two 19,000-L (5,000-gal) tanker trailers, with a separator reservoir and an atmosphere vent stack on the open end of the loop to boil off LN_2 drained from the cold wall. With a maximum tanker storage pressure of 60 psig, analysis indicated that the pressure-fed system would not provide sufficient flow to permit a pulse coil duty cycle of one 30-s pulse every 150 s. This limitation dictated that the PCCS be a pump-fed system.

A flow chart (Fig. 1) was then conceived to support a pump-fed PCCS. The major items of equipment in the PCCS include a subcooler, a vaporizer, two centrifugal pumps, vacuum-jacketed transfer lines, control valves, instrumentation, and controls. These items are arranged in a configuration that provides:

1. proximity to the existing LN_2 system control console for cryogen supply,
2. an elevated location for the subcooler to assist in providing a net positive suction head (NPSH) for the centrifugal pumps, and
3. short transfer lines from the subcooler to the pumps and from the pumps to the vacuum vessel penetration.

With the equipment located (Fig. 2), the vacuum-jacketed transfer lines were sized and dimensional isometric drawings were made of each segment of each line. A package of these drawings and a specification detailing the design requirements and acceptance criteria for each piece of equipment was prepared. This package was issued for competitive bid to industrial firms to perform detail design, fabrication, assembly, testing, and delivery of the specified equipment for installation by Union Carbide Corporation Nuclear Division. A single contract for all of the equipment was awarded to Cryogenic Engineering Company† (CEC) of Denver, Colorado.

Design Features

The main components of the PCCS are the pump station, the subcooler, and the vacuum-jacketed transfer lines.

Pump Station

The pump station is the heart of the PCCS. It consists of two centrifugal pumps, a vaporizer, connecting vacuum-jacketed lines with integral control valves, instrumentation, and local and remote control panels (Fig. 3). Each piece of equipment is located on a skid-type frame made from aluminum channels. When fully assembled, the pump station fits within the envelope dimensions of 3 m (10 ft) long by 2.4 m (8 ft) wide by 2.1 m (6 ft 9 in.) high. The dimensional requirements were dictated by space limitations and for ease in transportation and handling.

Centrifugal Pumps

Two pumps were chosen over a single pump to provide redundancy. In the event of a pump failure, both coils could be cooled from one pump at a shorter-pulse duty cycle. Each pump is designed to meet the following specified criteria:

Flow rate	3.15 L/s (50 gpm)
Total differential head	259 m (850 ft)
NPSH	1.53 m (5 ft) (max.)
Efficiency	50% (min.)

The pumps selected have a speed of 7100 rpm, an NPSH of 0.91 m (3 ft), and an efficiency of 52% and are driven by a 460-V, 3-phase, 60-Hz, 20-hp TEFC motor. Each pump is independently controlled from a control panel located on a building column near the

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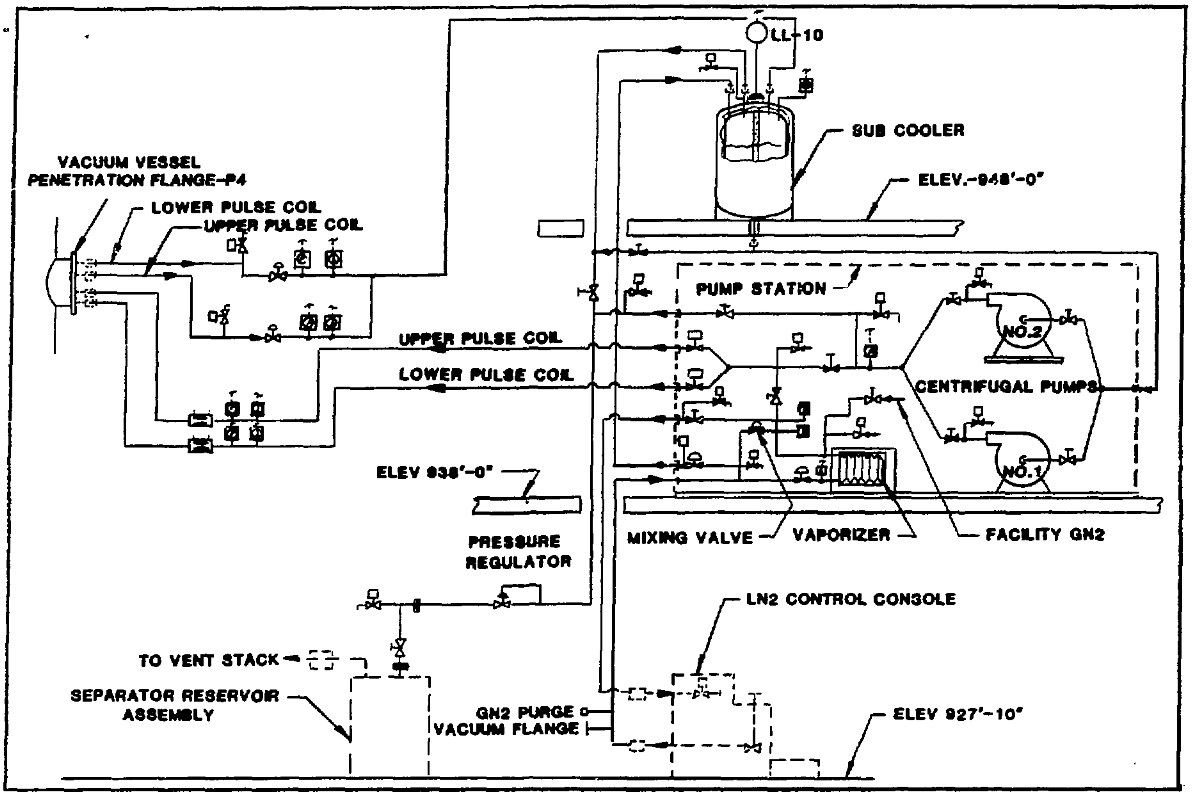

Fig. 1. PCCS flow chart.

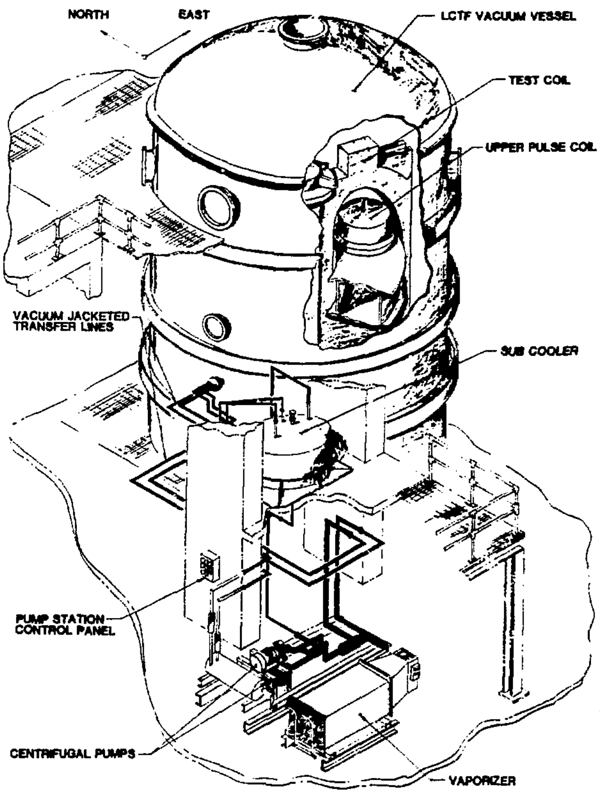

Fig. 2. LCTF at ORNL with PCCS equipment.

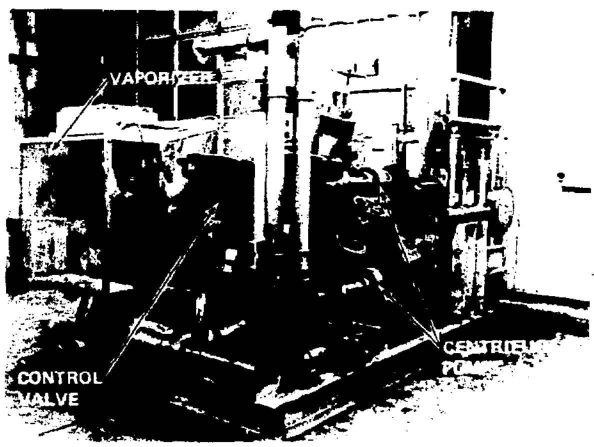

Fig. 3. Pump station (photo courtesy of Cryogenic Engineering Company).

pump station. The control panel also contains independent pump cavitation sensors, status and warning lights, an audible alarm, and reset switches. A second control panel with independent pump on-off controls and status and warning lights is located in the main LCTF control room for monitoring and emergency shutdown purposes. Each pump cavitation sensor operates a current relay that senses a set low current and shuts off power to the cavitating pump. The trip current is adjustable and is set during the initial installation and flow testing.

Vaporizer

The nitrogen was sized to cool both the pulse coils and the associated structure from room temperature to 80 K over a period of approximately 24 h, with the maximum differential temperature between the pulse coil inlet and outlet not to exceed 40 K. The vaporizer selected is an all-aluminum, ambient forced-air, ducted unit consisting of two banks of extruded finned tubes. Because the facility ceiling height is only 2.84 m (9 ft 4 in.), the air flow is horizontal. Each bank of finned tubes has a timer-controlled shutoff valve on the liquid supply side. The timer is set to flow one bank while the other bank is defrosting at 1-h intervals. A 2-speed, 32-in. diam fan is automatically controlled by an inlet manifold temperature sensor set to activate the fan at 227 K.

The vaporizer is designed to automatically provide a minimum of 20,000 scfh continuously with the gas outlet temperature not exceeding 60°F below the ambient air temperature. This output is with the air fan speed switch set on "slow" at ambient air conditions of 70°F and 30-40% relative humidity. Under the same conditions, the vaporizer output can be increased approximately one-third by setting the fan switch to "fast." A theoretical vaporizer performance curve is shown in Fig. 4.

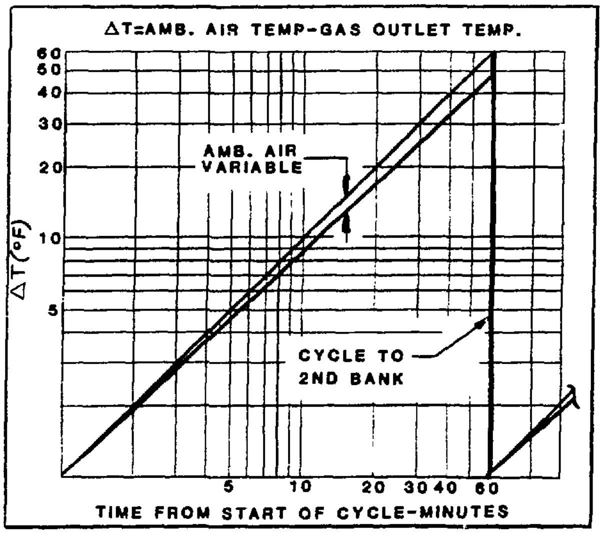

Fig. 4. Vaporizer performance (data provided by Thermax, Inc., South Dartmouth, Massachusetts).

The piping and valve configuration of the pump station was designed to allow simultaneous cooldown of the pulse coils, the centrifugal pumps, and the subcooler. In the cooldown mode, the PCCS valves provide a continuous path from the vaporizer outlet through the pulse coils and back through the subcooler centrigual pumps to a separator reservoir assembly that is vented to atmosphere (see Fig. 1). The vaporizer is provided with LN_2 from the main nitrogen control console at approximately 30 psig. With near-room-temperature nitrogen gas flow established at the vaporizer outlet and through the system, cooldown is initiated from the LCTF control room by mixing LN_2 with the vaporizer outlet gas through a remotely operated flow control valve. Temperature sensors located on the pulse coils and other parts of the PCCS will be monitored from the control room to maintain the cooldown rate within the prescribed temperature limits.

The pump station is also designed to cool down the LCTF vacuum vessel cold wall system and spider frame in a similar manner.

Subcooler

The function of the subcooler is to provide an elevated LN_2 supply source for the centrifugal pumps. The vacuum-jacketed tank has a 1000-L inner vessel built to the ASME Section VIII code (see Fig. 5). Both the inner and outer vessels are manufactured from type 304L stainless steel. The subcooler was designed for a maximum LN_2 boiloff rate of 2% per day. The actual boiloff rate, determined during predelivery testing, was approximately 1% per day. The subcooler is located approximately 3.7 m (12 ft) above the pump station and is connected to the suction side of the pumps by a short section of vacuum-jacketed pipe. The subcooler also serves as a receiver tank for the two-phase flow exiting the pulse coils. The liquid level in the subcooler is maintained near 75% of capacity with a variable capacitance probe that operates a flow control valve in the liquid supply line.

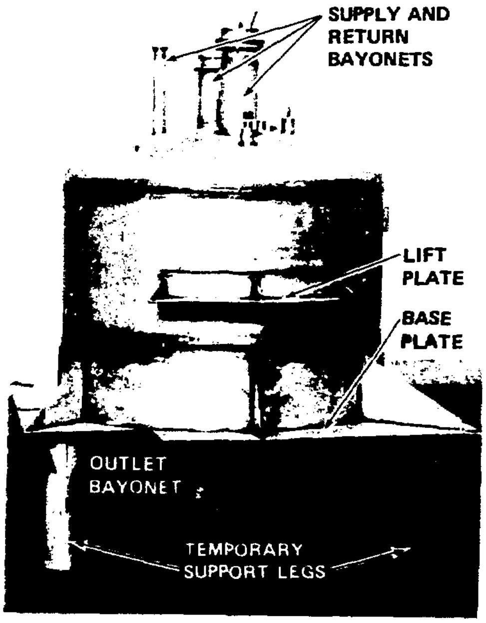

Fig. 5. Subcooler (photo courtesy of Cryogenic Engineering Company).

The subcooler vapor outlet is routed to the reservoir assembly through a 4-in. vacuum-jacketed line. A back pressure regulator valve (see Fig. 1) is installed in the vapor line to provide additional NPSH for the centrifugal pumps. The regulator valve has an adjustable range of 0 to 25 psig.

Vacuum-Jacketed Transfer Lines

Vacuum-jacketed transfer lines are used throughout the PCCS to provide the lowest quality (highest percent liquid) nitrogen to the pulse coils and to minimize consumption of liquid from the storage trailers. A total of 25 sections or spool pieces make up the transfer piping system. Each spool piece has its own integral vacuum with a pumpout port and vacuum gage tube to monitor vacuum levels. The spool pieces are joined by bayonet-type connectors. This system was selected over field-welded joints to reduce installation costs and for ease in troubleshooting and isolating leaks. Flexible sections in the inner and outer lines of each spool piece allow for a 2° freedom of movement for proper bayonet alignment.

The inner lines are wrapped with alternate layers of 0.25-mil-thick double aluminized Mylar and polyester fabric to minimize thermal radiation losses. Supports between the inner line and the outer jacket are fabricated from glass-filled Micarta (G-11). A fiberglass sock filled with activated charcoal serves as the gettering system in the vacuum annulus. Thermal stress relief is provided in each spool section by expansion bellows in the inner line.

To ensure leak-tight spool pieces with stable vacuum systems, the following practices were followed during production:

- visual inspection of all welds,
- radiographic inspection of 10% of all inner line welds,
- LN_2 cold shock of all inner line welds,
- helium leak test of all welds,
- evacuation of jacket while heating inner line to 130°C with intermittent 1-h dry nitrogen purges of vacuum space,
- a minimum of 5 days of continuous pumping with an oil diffusion pump to attain jacket vacuum levels of 1-5 μm,
- a monitoring period of 7 days with the vacuum pump disconnected, allowing no increase in vacuum level over the last 4 days that is not attributable to temperature change, with final pressure not to exceed 35 μm.

As a final check of manufacturing quality, a thermal performance test was performed on randomly selected spool pieces to measure the heat leak and compare it against a calculated value.

Acknowledgments

The authors wish to acknowledge the efforts of Cryogenic Engineering Company, which was responsible for the detail design, fabrication, and testing of all of the PCCS equipment, with special appreciation to George Gabert, who produced a major portion of the design and conducted all of the thermal performance tests.

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