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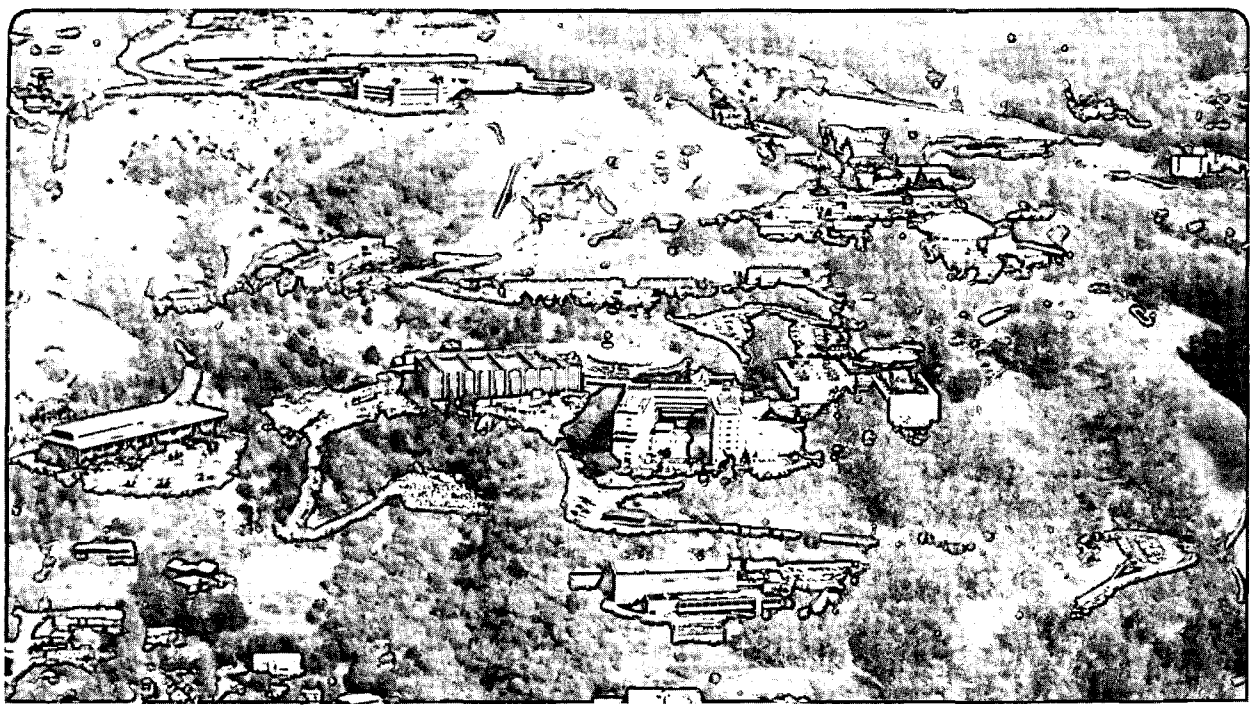

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HELIUM REFRIGERATOR FACILITY

Introduction

An experimental plant facility is proposed in order to conduct investigations pertaining to the development and testing of refrigeration systems for present and future cryogenic programs. The basic facility will permit experimentation in the area of advanced helium compressors. The screw compressor appears to have numerous advantages for use in relatively large helium refrigerator/liquefier systems, and a development program is proposed to realize these potential advantages.

This project will have significant bearing on cryogenic accelerator projects at this Laboratory as well as others. Examples include: PEP II (SLAC-LBL), ISABELLE (BNL), and the energy doubler (NAL). Apart from accelerator projects, other programs with projected cryogenic utilization may also benefit. Examples include electric power transmission and CTR programs.

The experimental results obtained from this development will provide clear specifications for refrigeration systems that can be used in future projects with a high degree of reliability. In addition, it is believed that the proposed experimental system, if successful, should result in considerable cost savings for future projects; this includes both capital and operating-maintenance costs. Prototype operational systems will be tested and evaluated under realistic conditions providing liquid helium to ESCAR (Experimental Superconducting Accelerator Ring) and a variety of other laboratory programs requiring cryogenics. Thus, in addition to the longer range projected benefits, the system can be tested and utilized with immediate laboratory programs.

Cryogenic Facility

The proposed facility will consist of a helium refrigerator/liquefier of approximately 1500 watts capacity at 4.2°K or 400 liters liquid helium/hour, or combination thereof. The major items will be the cold box, expanders, and a building enclosure (~ 30' x 30') with appropriate support pads and hoist equipment. The cold box, 8 ft dia. x 12 ft high, with high-vacuum insulation, will contain the heat exchangers and expanders. Controls and instrumentation will be sufficient for manual operation.

The size of the refrigerator plant is selected to realistically model future projects. While multiple units of this size are required for systems such as PEP II and the NAL energy doubler, the present ESCAR project at LBL is well matched for a single 1500 watt unit. As ESCAR is a development to build and test the world's first complete superconducting accelerator system, it will provide the most appropriate and comprehensive tests of the proposed cryogenic facility with full-scale operating requirements.

The cold box meeting the technical requirements of the proposed system is available from several manufacturers, will form the basic facility, and will be capitalized with plant funds. The evolution of the compressor system may involve the trial, development, and testing of a number of units as described below. This development will be supported by operating funds.

Justification of Need

A significant improvement in the state-of-the-art of liquid-helium refrigerator systems is required for future cryogenic accelerator systems. This development is important for future projects such as PEP II, which would utilize six or more systems of the size proposed here. Programs at other laboratories also project similar systems. Moreover, a meeting was held at LBL on May 21-23, 1974, to discuss the needs of the AEC's national laboratories for helium refrigerator systems in the proposed size range. Representatives from BNL, LASL, Oak Ridge, NBS, HEPL, and EPRI attended this meeting.

Systems of greater reliability than those presently available are required. Increased reliability will result in considerable improvement in machine operations, as well as savings in operational costs which are essential in the realization of programmatic goals. Therefore, the laboratory is undertaking a development program to advance the state-of-the-art significantly in order to have the necessary advanced technology for future high-energy physics proposals.

Compressor Development Program

Summary. It is proposed to develop a screw compressor system to supply the refrigerator cold box with gaseous helium. The compressor system must supply the refrigerator with 190-200 g/s of pure helium gas at a pressure of about 18 bar. This requires 750-800 HP compressors.

Although conventional reciprocating compressors are available in this size range, they are massive and bulky, and their reliability leaves much to be desired. In the last few years, a new line of rotary compressors has been developed, which are much smaller and potentially more reliable. These compressors are positive displacement dual-screw compressors. While screw compressors are available from some vendors, they have not been used for helium, as dry helium for cryogenic refrigeration is a particularly difficult gas to pump. Screw compressors offer a number of advantages over their more conventional counterparts, and initial cost estimates are quite favorable.

Background. Historically, the standard laboratory, intermediate or large size cryogenic refrigerator/liquefier has been assembled with reciprocating, positive-displacement compressors. The reciprocating compressor has many disadvantages, especially in the areas of capital, installation, and operation costs as well as complexity. The large size required by multiple cylinder layouts, the high shaking loads and the difficulties in lubrication, oil removal and wear rates create particular problems for many special cryogenic applications. Now with the incipient growth and application of superconducting devices in many areas, incentives are

increasing for the development of an inexpensive, reliable, compact (even semi-portable) compressor system.

With the standard reciprocating compressor, the designer has two choices--lubricated or non-lubed. The lubed system can be operated for long periods between maintenance, but it requires an absolute oil-removal system. Also, the oil-injection must be carefully adjusted for the proper balance between rapid ring wear and flooding the clean-up system. For the non-lubed case, one can select filled Teflon (fluorcarbon) seal rings with their frequent maintenance periods or labyrinth seals with their high-leakage rates.

Rotary-type compressors have the potential for compactness, simplicity, and high reliability, minimal vibration and relatively low cost. In the rotary group, centrifugal compressors are unique because they create pressure by velocity increase. They are not positive displacement, and hence subject to much slippage. This is their primary disadvantage, especially in the cryogenic application. Centrifugal machines can offer the advantages of oil-free gas and no wearing parts in the process stream, but for low-density gases they require many stages to reach the higher pressures, and very high-tip speeds, with highly stressed and precision-balanced rotors.

In the rotary positive-displacement compressor group, various types are available: rotary screw, lobe or Roots-type, water-ring and sliding vane. All of these machines have similar performance curves to those of reciprocating compressors: fixed capacity with variable back pressure. The water-ring isolates the process gas from the rotating metal parts and provides excellent cooling but introduces other problems with water vapor removal and potential heating malfunction. The sliding vane type requires oil lubrication and has high-wear parts in the process stream. The lobe or Roots and the rotary screw type seem the best of the group because they can deliver oil-free gas and have no wear parts in the stream. The design gives them a through-put capacity much larger than reciprocating units without pulsation problems.

Advantages of the Rotary-Screw Compressor. The rotary-screw compressor is the most attractive system for development because of the following advantages:

1. High Efficiency: The efficiency characteristics curve is relatively flat with excellent operation over a wide range of conditions. The efficiency does not decrease with time because there are no wearing parts to reduce the through-put.

2. Mechanically simple - High reliability: Few working parts result in a design for long, continuous operation. The screws are very rugged, lightly stressed and insensitive to shocks and overload.

3. Low maintenance: Elimination of wearing parts such as valves, rings, cylinders and liners extends life and minimizes maintenance costs.

4. Oil-free delivery: The machine has the potential for oil-free gas delivery; however, for helium, this will depend on the results of the development program.

5. Compact, light weight: The small size and low weight result in reduced building and foundation costs. Skid mounting is feasible for flexibility.

6. Minimum vibration: ~~Free~~ Absence of unbalanced forces, and high amplitude vibration eliminates the need for heavy foundations, and ~~does not~~ prevents damage to surrounding piping and instruments.

7. Stable performance: Positive displacement allows the unit to operate over a wide range in compression ratio, speed and gas density with stable discharge and without the pulsation of reciprocating units or the surge of centrifugals. This stability permits easy operation with other compressors in parallel or series.

8. Drive flexibility: Adaptable to high-speed electric motors, gas or diesel engines, gas or steam turbines. Direct drive and vari-speed

8. (Continued)

is possible. The adaptability over a wide range of speed and performance makes the machine especially desirable for a development and research study in an expanding technology.

9. Cost Savings: Relative to reciprocating units (1500 watt size-range), capital cost reductions of ~ $150,000/unit are estimated. As 10 to 25 units are projected for various projects in the next few years, this can amount to $1.5 - 4 million in capital cost alone. With minimization of wear and optimized reliability, operating and maintenance cost savings can easily approach or exceed the above capital cost savings. Also, the flexibility of a semi-portable skid-mounted compressor permits minimal redundancy and standby units for widely separated cryogenic stations.

Experimental Program. The steps in the experimental program development are outlined below:

1. Manufacturer and Trade Survey. Discussion and study with rotary screw compressor vendors and users. The screw compressor is a rather recent (10 years) development and has not been developed for helium systems of the size required here.

2. Compressor Design Study. The gases used for low-temperature work--hydrogen and helium--create problems because of their low density (high leakage, slippage, low oil entrainment for lubrication) and high specific heat ratios. This means that for helium, if the compression ratio is too high, the heating can be severe and adequate cooling must be provided. A design balance must be reached between number of stage and balanced cooling of components. A number of variations will be considered.

3. Purchase of First Model for Helium Conversion. This will be a full-scale unit, large enough for 1500 watts refrigeration at $4^{o}K$ (or

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dependent on system and redundancy design purchase of 50% compressor capacity). Whereas some preliminary work could be done with small models, anything less than a full-scale final test of the complete system could only furnish incomplete information subject to challenge. Subsequent units may be required, depending on the experimental results.

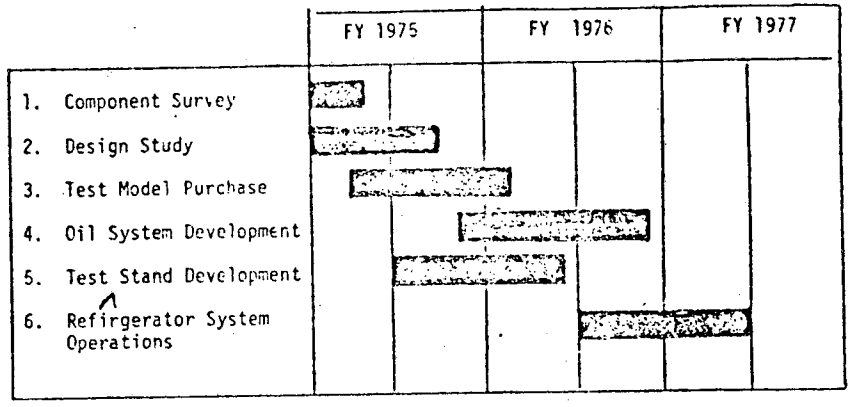
4. Oil/Coolant System Development. Some industrial techniques are available, but overall system will require design, assembly, testing and evaluation. One technique, used for small commercial units, injects cooled oil directly into the process stream, cools it, removes it completely downstream, and returns it to the closed cycle. This technique permits a closer approach to isothermal compression and provides full ring and cylinder lubrication. Ideally, it would be best to eliminate oil completely from the process stream; but if that is not possible, then a satisfactory clean-up system must be developed. Various techniques will be investigated.

5. Test Stand Development: Operation on closed-loop system with full flow and load (and overloads). Operation without process stream oil or other fluid (kerosene, H_2O) contaminant if possible. Depends greatly on gas slippage, number of stages, and heating.

6. Incorporation of Compressor Operation with Helium Refrigeration and Loads. This would involve operation of the complete system, compressor(s), refrigerator and loads (e.g., ESCAR) and would constitute a final examination and proof of the system. Unattended, continuous operation of something like 6000-8000 hours will be the objective.

Schedule & Costs

A project schedule for the development is as follows:



Estimates for the capital and developments costs are shown in Table I and II. Operational costs for Test Stand Development and refrigeration system operations of course depend on the success of various stages of the initial development program, and the best estimates for FY 76 and FY 77 are provided.

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TABLE I

CAPITAL COST ESTIMATE -

Item	K$
1. Cold box: outside fabrication, 1500 watts @ 4.2°K, includes engineering, heat exchangers, expanders, vacuum insulation, instrumentation	375
2. Building:* Steel frame, approx. 30 ft × 30 ft × 16 ft high, includes compressor pads and sprinkler system	30
3. Installation* Includes elec. power feed and lights; water, helium, air piping; millwright labor and hoist equipment	75
TOTAL GENERAL PLANT	480

* including engineering and contingency.

TABLE II

DEVELOPMENT COST ESTIMATE

FY 75	
Compressor(s) 750/800 HP, 2200/2400 CFM, 15/20 atm. includes motor, etc.	95
Oil system and development	70
TOTAL	165
FY 76	
Oil System and Test Stand Development	140
System Operations	100
TOTAL	240
FY 77	
System Operations	120

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Alternate Possibilities

There is no existing commercial compressor package with the required reliability suitable for helium cryogenic refrigerators in the 500-1000 H.P. range. A contract for commercial development of such a unit would require several hundred thousand dollars in additional funds over the costs outlined above.

Hazard Protection Measures

This project, like all Laboratory construction, will be designed, engineered, and built in conformance with the requirements of the all-applicable codes, including the Uniform Building Code, the National Electrical Code, the National Plumbing Code, the State Industrial Safety Orders, and the regulations of the State Fire Marshal. The plans will be reviewed by the University Office of Environmental Health and Safety.

The Laboratory Safety Office will insure that adequate safety standards are maintained in the course of construction. This responsibility includes such functions as checking scaffolding, determining the need for fire watchers during welding and burning operations, furnishing fire protection as needed, and checking the project site for hazards.

A preliminary survey of operational safety considerations has been made by the appropriate LBL safety personnel, as required by AEC Appendix 6101. The following evaluations reflect the current state of knowledge and planning relating to operational safety. Further study and developments will contribute to the safe design and operation of this facility.

1. Radiation
   There are no associated radiation hazards.

2. Fire
   A fire-detection and sprinkler system will be installed. Fire call boxes are already located near the site and provide full reporting

2. (Continued)

   coverage. The danger of electrical fire is minimal. Flammable gas hazards will not be present. Design in strict accord with applicable AEC, National and State Safety and Building Codes will neutralize possible hazards.

   Laboratory fire protection facilities are well developed and equipped to handle most fires and emergencies. The Berkeley Fire Department and the Oakland Fire Department are also on call.

3. Pollution

   No solid, liquid or air pollutants will be generated by this operation. The drain from the support ground floor will be manifolded to a separator-retention tank to control the disposal of waste oil or other liquids in case of an inadvertent spill.

4. Other Features

   a. Safety latches on crane hooks and limit stops on crane rails, plus other standard crane safety features, will be provided.

   b. Emergency lighting, in addition to adequate area lighting, will be provided.

   c. Adequate vehicle passage will be provided around the facility. Control of traffic flow will minimize vehicular hazards.

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