FERMILAB-TM-2638

Fermilab

FERMILAB CRYOGENIC WORKSHOP

REPORT

JUNE 1980

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Preface

A workshop to discuss recent pressing problems experienced in the operation of helium refrigerators at the national laboratories was proposed by DOE. Early in 1980 it was decided that the workshop should be held at the Fermi National Accelerator Laboratory (Fermilab). The reasoning behind the selection of Fermilab included the proposed initial tests of the Central Liquefier, the recently experienced problems with refrigeration systems at Fermilab, and the fact that a previous workshop had been held at the Brookhaven National Laboratory, which, at present, would be the other logical choice for the workshop.

The workshop was rather hastily conceived; the first meeting of the organizing committee was on May 26, 1980. It is hoped that no interested parties were overlooked in the selection of individuals invited and institutions represented.

The workshop at this immediate perspective appears to have been very successful. Both users and manufacturers arrived with relevant information and open minds. The session chairmen appear to have guided their groups into penetrating discussions of existing problems and potential solutions, avoiding the pitfalls of dwelling on successes.

These proceedings were assembled during the twenty-four hours following the workshop and contain only a fraction of the information presented. No attempt has been made to bring the diverse inputs into a consistent format. The primary purpose of this document is to make available to all interested parties, as quickly as possible, a summary

Summary from Working Group 1

W. Cooper

Fermilab

Screw Compressors and Oil Removal

I. Compressors

Commercial screw compressors are available from the three major manufacturers (Dunham-Bush, Mycom, and Sullair) in the range 100 CFM to 3000 CFM. The construction of compressors for ammonia/freon service and helium service is generally the same. Sullair has an additional seal for helium service which bascially provides a sealed volume between the main shaft seal and atmosphere to enable monitoring of the main seal performance. This also minimizes the amount of external dirt, etc., which can reach the outside of the main seal.

All manufacturers claimed their compressors were suitable for sub-atmospheric operation. Dunham-Bush has available semi-hermetically sealed compressor/motor packages which eliminate the shaft-seal leakage problems. These compressors appear to be well suited to sub-atmospheric operation. There is some information available on the performance of other compressors from experiences people have had in pumping down the compressor system. Mycom compressors have shown shaft-seal leakage under vacuum. Sullair compressors leak at mating surfaces on the oil pump under vacuum. Both Dunham-Bush and Sullair compressors can be pumped down to 50 microns, but in the Sullair case, only after the oil-pump leakage problems are eliminated.

by Arthur D. Little. The compressor uses two approximately concentric scrolls (helixes): one is fixed and the other is moved by an eccentric type drive. The scrolls are internally cooled with water. The prototype model has two stages giving a volume ratio of 16:1. The flow is 85 SCFM with an input power of 27 kW. The drive speed is 1800 rpm. The compressor has been operated about 270 h. Noise and vibration levels are relatively high compared to expectations.

The second compressor is being developed by Mechanical Technology Incorporated. It has a linear motor drive, dual opposed pistons (one on either end of the shuttle shaft), gas bearings, and gas spring volumes at either side of the motor. The pistons are ceramic coated and ringless. They operate with about 0.001" clearance and are unlubricated. Piston diameter is about 4". Flow is 60 SCFM with a 4:1 volume ratio. The compressor can be hermatically sealed. The motor drive is resonant and runs between 50 and 100 Hz.

II. <u>Oil Removal</u>

There was substantial discussion of vapor pressures; much of the information was supplied by Bill Martin of Union Carbide and is included as a separate section of this report.

The question of vapor pressures and the utility of charcoal beds was unresolved. If the vapor pressure estimates are correct, then there is negligible vapor for charcoal to remove. Furthermore, charcoal may be ineffective in removing light-end oils. R. Strauss (Balston) said that he would attempt to measure vapor removal efficiency for charcoal

The weakest link in oil removal appears to be in the bulk oil separators. Output oil levels of 30 PPM to 3000 PPM were reported. The higher levels in many cases were traced to poorly sealed coalescing elements in the bulk separators.

Because of these problems, demister manufacturers recommend that systems be designed to accommodate 1000 PPM to 5000 PPM from the bulk oil separator.

Both Balston and Monsanto demisters are reported to work satisfactorily. Recommended helium velocity through the coalescer is recommended to be 20 ft/min maximum. Monsanto recommends a maximum velocity parallel to the outside of the coalescer (assuming inside to outside flow) of 10 to 20 ft/sec (?). This determines the space needed between the coalescer and outer housing.

Finite filters (Finair Company) are reported to work comparably to Balston filters. They are similar in manufacture and there are some patent infringement questions.

It was pointed out by R. Strauss (Balston) that oil retention efficiency should be specified at the minimum of the retention versus droplet size curve (0.3 to 0.6 microns). These efficiencies assume that oil is able to drain from the coalescer at a greater rate than that at which it is collected. This means that at excessively high input oil levels, re-entrainment can occur with a resultant degradation of efficiency. It was also pointed out that efficiencies of successive stages of identical filters will be lower, because those droplets easiest to remove will already be absent.

UCON LB-170X Lubricant for Oil Flooded Screw Compressors

W. H. Martin

Union Carbide Corporation

In considering the characteristics of LB-170X, it is necessary to take into account the nature of the material.

1. UCON LB-170X is an alcohol started polypropylene glycol:

   $C_4H_9(OC_3H_6)_n$ - OH

   Average Molecular Wt. ∿ 730

   Viscosity, SUS @ 100^oF = 170

   (This oil is also produced in other viscosity ranges such as LB-140X, LB-300X, LB-400X, LB-650X, LB-1200X, and LB-1800X.)

2. UCON LB-170X is not a simple compound, but is a mixture of oligomers with a range of molecular weights and vapor pressures.

3. UCON LB-170X is a production chemical, undoubtedly containing residual amounts of impurities, some of which may be more volatile than the oligomers themselves. Additional trace impurities, such as nitrogen, may be picked up during transport and storage. The oxidation inhibitor, may have enough vapor pressure to add appreciably to the total pressure exerted by the LB-170X. The sparse experimental data indicate the inhibitor's contribution to the vapor pressure is negligible.

4. As marketed, UCON LB-170X contains 1500 to 2000 PPM water.

vapor pressure at 25°C. However, the Poisson-distribution calculation indicates that appreciable amounts of species with significant vapor pressures are present. For example, the first members of the series should be present at the mole fractions and pressures shown below:

Species	X (mole fraction)	P (mmHg) P 25°C
$C_4H_9\ (OC_3H_6) - OH$	2.2×10^{4}	1.0×10^{3}
$C_4H_9\ (OC_3H_6)_2 - OH$	3.3×10^{4}	6.1×10^{5}
$C_4H_9(OC_3H_6)_3 - OH$	1.3×10^{3}	2.2×10^{6}

This is in disagreement with the best experimental data on the known vapor pressures, which were obtained some years ago with production UCON fluids using the Knudsen effusion method. Whereas LB-170X per se was not examined, the interpolation between the values shown is well justified. Firstly, however, one should understand that UCON LB-170X is derived (formulated) from UCON LB-165 and on a viscosity (molecular weight) graduation, UCON LB-165 obviously falls between UCON LB-135 and LB-285.

UCON Lubricant	Average Molecular Weight	Vapor Pressure, mmHg at: 25°C(b)	122°C(a)	150°C(a)	250°C(b)
LB-135	660	1×10^{-11}	1×10^{-6}	9×10^{-6}	1×10^{-3}
LB-285	860	1×10^{-11}	7×10^{-7}	5×10^{-6}	1×10^{-3}

(a) experimental results.

(b) Extrapolated data; order of magnitude only.

NOTE: Vapor pressure data at 122°C and 150°C are considered precise to $\pm$ 0.5 x 10^{-n} mmHg.

Separate studies with LB-285 indicated that addition of the antioxidant did not alter the numbers for the base fluid.

present, so oxidative attack can probably be ignored. Thermal stability of these structures is good and probably not a factor below 350°F (175°C). It should be noted that this has never been documented and detailed analysis of UCON LB-170X after several thousand hours use is needed.

4. Water absorbed by UCON LB-170X is not necessarily free water as strong hydrogen bonding occurs between the terminal hydroxyl group of the UCON structure and water. (The Karl Fisher Technique measures both free and hydrogen bonded water.) In our experience it is extremely hard to remove water from these products due to this association. The lowest concentration of water, achieved after several days flow through molecular seive was 200 PPM. Although 200 PPM water, if free as in an oil, would cause problems in refrigeration systems this should not be the case with UCON LB-170X.

5. Union Carbide will soon identify, qualitatively and quantitatively, the impurities in LB-170X and will assess the capability of applying special treatments before delivery.

Monsanto Enviro-Chem Systems Incorporated

J. R. Owen and E. Kennedy

Two fiber bed filters were tested with dioctyl pthalate (DOP) according to the procedure described below:

1. The filters were bolted to a plywood flange with a neoprene gasket coated with silicone grease to improve the seal.
2. A small Spencer turbine was used - rated at 50 CFM at 12 oz. It was used to suck the air and DOP from the inside of the filter to the outside. A ¼" sample port was located next to the inlet for sampling the upstream side. The downstream side was sampled at the discharge of the turbine.
3. A sheet metal housing with cover was mounted around the unit and sealed.
4. The tests were first conducted with a polydispersed aerosol of DOP droplets (mean diameter of 0.7 μ) using a Sinclair-Phoenix photometer, Model #J2000. The tests were repeated with a thermal DOP generator (Air Techniques, Incorporated, Model No. TDA-5A), using a monodispersed DOP aerosol having a mean particle size of 0.3 μm and using a linear-readout photometer, ATI Model No. TDA-2C.

   The results are as follow:

	Efficiency in %	
	Std. Filter	Hi-Density Filter
0.7 μm DOP	99.9+	99.985
0.3 μm DOP	--	99.994
< 0.3 μm DOP (Design)	99.7	99.97

Activated Carbon Adsorbent

J. Satti

Fermilab

The table summarizing characteristics of various types of activated carbon was presented by J. Satti of Fermilab.

Optimizing Compressor System Efficiency

A. Fresco

BNL

The objective of any positive displacement compressor is to avoid undercompression and overcompression in order to obtain peak efficiency.

The desired pressure and volume are obtained because the local stagnation pressure at the discharge of the compressor is determined by the conditions in the downstream piping and is the same whether the compressor overcompresses or undercompresses.

By injecting oil into the gas stream, the compression process can no longer be considered an adiabatic process. In the case of helium or any gas with a ratio of specific heats, k, much greater than 1.0, the deviation from adiabatic is extreme. The process is more closely governed by the equations for a polytropic process:

$$p\,V^n = C \text{ where } n = \frac{\log(p_1/p_2)}{\log(V_2/V_1)}$$

For any process, the isothermal work is the ideal minimum work to compress a gas through a given pressure ratio, $P_r = p_2/p_1$. The isothermal equation is $pV = C$, which equals the polytropic equation $pV^n = C$ for $n = 1.0$. The closer the real process approaches an exponent $n = 1.0$, the more efficient the compression. For any gas, the discharge temperature of the gas is usually kept between 160°F to 212°F. Generally, n turns out to be about 1.10 although it can be as low as 1.05 or as high as 1.15.

Expansion Engine Development, Group 2

R. Gibbs, Chairman

BNL

The following summaries prepared by the participants are submitted.

With respect to improving turbine repair turnaround time, HELIX is working towards that end by either stocking spares or having a repair facility in the United States.

We have observed degraded performance of heat exchangers that are purposely mounted upside down for ease of piping. The change in density affects the friction pressure drop in the exchanger.

An area that has not been discussed adequately is the design of phase separators that serve the dual purpose of phase separator and calorimeter. A careful design analysis will avoid entrainment of liquid back into the heat exchanger.

We have recently encountered some difficulty in obtaining very large 8-10" diameter cryogenic valves, which are usually slightly modified standard valves, particularly for the ISABELLE program.

Table I

Helium Liquefier Operation to 10/1/76

Total Operating Time	20,000 hrs.
Approximate Continuous Running Time Between Shutdowns	3 Months or 2160 hrs.
Current Maximum Liquefaction Rate (attended) . .	120 ℓ/hr
Average Liquefaction Rate (unattended)	85 ℓ/hr

Specifications

Cycle Type	Claude With LN_2 Precool
Compressor	
Manufacturer	Rix Industries
Type	DBG 1050 Reciprocating, non-lubricated, vertical
Number of Stages	2
Flow Rate (SCFM)	
(14.7 psia, 70^{o}F)	850
Power Consumed (hp)	275
Expander	
Type	Radial Inflow Turbine
Model	185 H
Speed (rps)	4000
Bearing Type	Hydrostatic Gas Lubricated
Operating Characteristics	
Inlet Temperature (K)	18
Flow Rate (SCFM)	465
Isentropic Efficiency (%)	65
Refrigeration Produced (watts)	1220

Recent Turbine Failures at LBL

P. Eberhard

LBL

There were three turbine failures at LBL in the last two years on a CTI-Sulzer 1500 W refrigerator. All failures were in the upper turbine; only ambient temperature purifiers were used at the time of failure.

The Fall 1979 failures were identified as caused by a 200 μm offset of the turbine axis in the nozzle. This problem was recognized after failure #2 by pieces of metal deposited in the nozzle. It was cured by remachining the nozzle off-center!

Two causes of the February 1980 failure are considered possible:

1. water leak through an internal O-ring seal,
2. oxygen contamination.

Evidence in favor of #1 is the weak design of the seal. Evidences in favor of #2 are:

1. the refrigerator was cooled twice without load and presumably without appreciable contamination,
2. 300 PPM O_2 and 110 PPM N_2 were found in the load,
3. the failure occurred when the cooling load was connected to the refrigerator at 49K (i.e. at a temperature corresponding to an O_2 vapor pressure equivalent to the measured contamination.

The following possible cures have been found for these problems.

1. The turbine was returned to Sulzer to modify the seal.
2. An 80K purifier was added in the system.

Helium Ejectors

T. R. Strobridge

NBS Boulder

Helium Ejectors

For several years, helium ejectors have routinely provided supercritical helium at 3.6K for ISABELLE magnet cooling. While the first device did not meet the design performance, the present unit exceeds the design pumped - pressure ratio of 0.36 by 30%, exceeds design entrainment ratio of 0.16 by 56%, and has operated for many hours without a failure.

Reliability

In 1973 Fermilab commissioned NBS to visit the large helium extraction and liquefaction plants in Kansas and Oklahoma to discuss failure modes with the owners and operators. To our knowledge, these few data, which are given partly below, comprise the only data base - if it can be called a data base - for large helium refrigerator failure experience.

Actually, much more data resides in the laboratories within DOE. We feel that it would be of great benefit to compile the information from all the bubble chamber and other cryogenics machinery that has been operating for years. A continuing data gathering scheme should be established. These data would then be available to the large projects for reliability analyses and could result in potentially large savings.

II. EQUIPMENT

1. EXPANDERS

A. Rotary

Helium, two turbo expanders in series

Design and operating conditions:

- Flow
  - High pressure unit - 200,000 SCFH
  - Low pressure unit - 200,000 SCFH + some of 70,000 SCFH
- Inlet
  - High pressure unit - 120 psig, 34.3 K
  - Low pressure unit - 45 psig, 14.3 K
- Discharge
  - High pressure unit - 45 psig, 27.6 K
  - Low pressure unit - 4.4 psig, 9.83 K
- Maximum speed
  - High pressure unit - 95,000 rpm, 80,000 nominal
  - Low pressure unit - 85,000 rpm, 54,000 nominal
- Power dissipation - Oil brake
- Wheel sizes
  - High pressure unit - 1.77 in.
  - Low pressure unit - 1.97 in.
- Bearings - Pressure lubricated oil journal and thrust bearings
- Wheel and nozzle - Radial inflow, axial outflow, fixed nozzle blades, full admission
- Seals - Labyrinth and seal gas

Maintenance schedule - None

B. Reciprocating

Helium - One, two cylinder, two phase exhaust

Design and operating conditions

- Flow
  - Warm cylinder - 70,000 SCFH
  - Cold cylinder - 27,000 SCFH plus flashing loss
- Inlet
  - Warm cylinder - 210 psig
  - Cold cylinder - 45 psig

Two complete turbines are kept as spares along with seven sets of rotors and bearings. (The spare parts inventory at this facility was extensive for all the machinery.) Repairs are made by the manufacturer. Since the initial operation, there has been no outside technical assistance for the turbines.

B. Reciprocating - A total of 4840 operating hours have been accumulated on the two phase exhaust expansion engine. During that time, two valve seal retaining screws have fallen into the cylinders ruining pistons. At about 3000 hours, repairs to the valve cams were required. The cam repairs were made by the plant maintenance men who feel a wider key and keyway would alleviate the problem. The manufacturer has been very cooperative and in general, the machine is quite satisfactory. It is easy to start and stop, taking about 1.5 hours to cool down and bring on line.

2. COLD BOX AND HEAT EXCHANGERS

There have been no problems with the cold box and heat exchangers although the bottom 4 feet of the dewar were frosted as was part of the large storage dewar. Evidently, the production rate is satisfactory and the heat leak is not considered excessive.

3. COMPRESSORS

The dry lubricated helium compressors are shut down and inspected for ring wear every 90 days. Typical ring life is 9 months. Difficulties with wear particles traveling to the liquefier prompted the installation of three sets of filters-- the last one is 10 μ, operating at 80 K. All of the natural gas motor-compressors were re-bored after 6 years of service.

Valve life on the diaphragm compressors was about 1 month. However, decreasing the valve plate travel has helped considerably. Diaphragm life is typically 2500 hours. Since the plant was started, one crankshaft was bent and one piston seized. The manufacturer assisted with the seized piston.

IV. GENERAL ADVICE BY FACILITY PERSONNEL

1. Adequate adsorption capacity is an absolute necessity. Impure process gas has been the biggest problem.
2. Good maintenance personnel and careful operators are the key to successful operation.
3. The plant equipment is well suited to the company's requirements.

6. Adaptation of commercial oil-lubricated compressors, hermetic and semi-hermitic, 1/4 HP to 80 HP; reciprocating, rotary vane, and rotary screw.
7. Present APCI activity in new helium level machinery includes several different reciprocating and turboexpander devices for a new 1400 ℓ/h APCI helium production plant in Texas.

In addition to the foregoing small refrigerator machinery, APCI also designs and builds a broad line of custom cryogenic turboexpanders of all styles (approximately 600 total units to date).

The new Gardner Cryogenics Department of APCI is a builder of helium transport containers and semi-trailers.

Problems Discussed

1. Pounding/spalling damage of metal poppet valves.
2. High wear on cold valve guide bushings.
3. Cold valve spring side kick and rubbing.
4. Seizure of close clearance metal-to-metal pistons.
5. Loosening of spline drive in oscillating service.
6. Cold valve abnormal operation, valve spring related.
7. General abrasive wear-charcoal carry through.
8. System plugging-oil carry over.
9. Age old problems are: what does customer really want; what is most appropriate balance of cost versus features; how can a continuing quality control effort be maintained at the point of fabrication.

In a recent run, helium cooled by LN_2 was used to thermodynamically replace the #1 turbine and the refrigerator produced at its design levels

Two Sullair compressors are used in parallel to produce 100 g/s of flow for this plant. An electric motor failure (bearing) is the only significant problem, to date, with these compressors.

Operating Problems

Operability and Staffing: The machine is difficult to operate; yet the extent of operation does not justify full staffing. Problems arise during warmup and cooldown and occasionally at other times. A computer monitoring system is very helpful during steady-state operation.

Inventory Handling and Control: The facilities are expensive, filling and storage are both time consuming. Helium losses are difficult to troubleshoot quickly and vigilance is always required.

Equipment Problems

Contamination: There are many sources of contamination not just the sub-atmospheric parts of a system. For example, piston rod drag-in is serious. The full-flow LN-cooled charcoal purifier is suitable for initial clean-up, but is ineffective for long-term, low-level contamination control. Switchable charcoal traps in cold box at 60K are much more effective. This problem is a persistent and difficult one and must be attacked by all means available. There is no substitute for regular warmup once or twice a year.

For absorption at a partial pressure of 10 microns or less (.5 PPM v/v) charcoal at 77K has a very limited capacity. At 50K the capacity is 300 times greater.

The following changes and observations have been made in the system and procedures.

1. Computer monitoring for operability.
2. Liquid helium storage has been added.
3. Re-staged and modified roots pumps.

Operating Experience With the Fermilab Central Helium Liquefier

H. Barton, M. Price, R. K. Rihel, R. J. Walker
Fermilab

I. Introduction

The Fermilab Central Helium Liquefier produced liquid helium for the first time recently. Operation was with a closed cycle in the plant and no flow to the ring or satellites. Most of the main systems were tested. The following systems are essentially operational:

1. Two Main Helium Compressors
2. Interstage and After Coolers
3. Switchgear for Compressors
4. Controls for Compressors and Cold Box
5. Helium Cold Box Including Turbo-Expanders and Heat Exchangers
6. Cryogenic Purifier
7. Liquid Nitrogen System
8. Oil Removal Equipment

II. Compressor Operation

The helium compressors are rehabilitated 4000 hp air compressors from a LOX plant built by Air Products Company for the U.S. Air Force at the Rocketdyne Test Facility in the Santa Susanna Mountains just north of Los Angeles, California. They were reconditioned and refitted with carbon-filled Teflon rings and packings by a local compressor firm. Current performance is above the design parameters. The compressors, which have operated for about 400 h, are relatively quiet with little vibration.

valves. The alarm system is centralized in the second floor control room and includes a Texas Instrument Model 5000 programmable sequencer and an interactive data panel.

III. Cool-Down and Liquid Production

Initial attempts to cool the plant were foiled by turbo-expander problems. The turbines would turn, but at a fixed brake setting they would oscillate in speed with a period of a few seconds. The turbines were then taken out and the rotors polished or replaced. The problem was blamed on dirt in the oil system. A longer run of about two days was judged to be adequate to clean the oil system. The turbine speeds were still unstable, however. At this time turbine 3 suffered a destructive overspeed during one of the excursions in speed. This time we cleaned even more vigorously, including reworking the pipes between the turbines and the oil skid.

In spite of our best efforts, the turbines were unstable. The system was cooled with the turbines running at low speed, which resulted in a cautious 14 h cooldown. As the system approached operating temperature, it was possible to increase turbine speed and efficiency somewhat without undue instability.

At this time we decided to take the system through as many thermal cycles as possible during the scheduled week of operation. Four cool-down cycles were completed. Peak production of 3000 ℓ/h was observed and continuous production of 2700 ℓ/h was recorded. This rate was measured at 76% of compressor capacity.

Satellite Refrigerator Expanders

T. Peterson

Fermilab

I. A unique problem which we have, briefly stated, is that we have to simultaneously operate 48 helium reciprocating expanders.

II. Each of the 24 satellite refrigerators has one "wet" and one "dry" engine with the following requirements.

A. The dry engine expands approximately 12 to 29 g/sec of 30°K, 20 atm helium to 1.2 atm, 15°K.

B. The wet engine expands as much as 53 g/sec of 6°K, 20 atm helium to 1.8 atm two-phase fluid (4.9°K).

III. Two quite different designs will be used for both the wet and dry engines.

A. One is a reverse-engineered Gardner engine (referred to as a Gardner-Fermi).

B. The other is the CTI-1400 model expander.

IV. Running experience so far is limited to a few thousand hours on the Gardner-Fermi and the CTI wet and about 500 hours on the CTI dry.

Cyclic Heat Transfer in Engine Cylinders

Joseph Smith, Jr.

MIT

Work is in progress at the MIT Cryogenic Engineering Laboratory to evaluate the influence of heat flow between a gas and the cylinder wall. This heat transfer causes the expander to accept more gas for a given indicated work output. In effect, the heat capacity of the cylinder wall acts as a thermal regenerator in the inlet gas stream between expander inlet and expander outlet. The undesirable effect of steady heat transfer between inlet and outlet is well recognized, but this regenerative effect has not been studied.

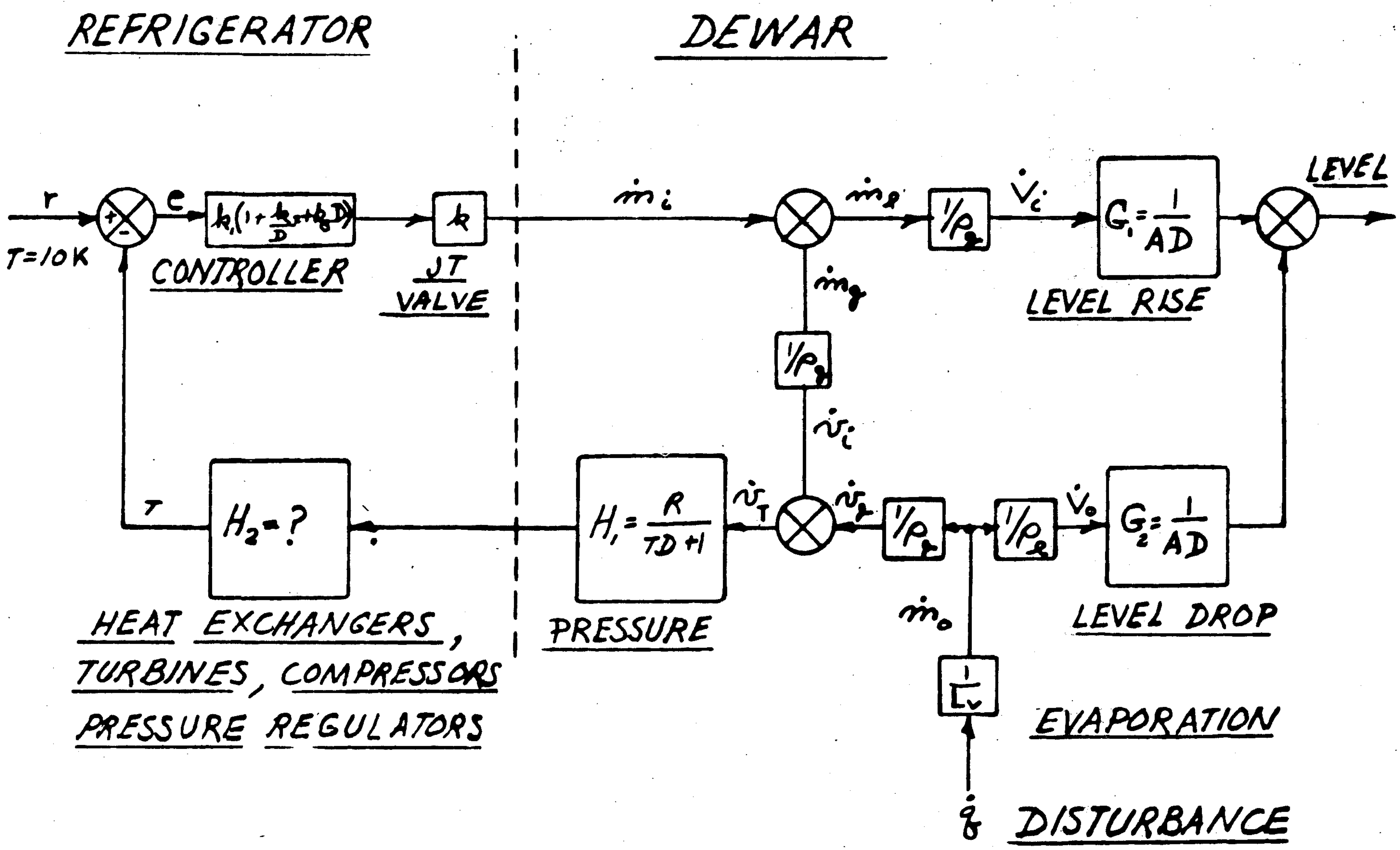
In order to understand the process a simple experiment is being done in a closed cylinder to measure the cyclic heat transfer by P-V measurements. For one geometry (fixed volume ratio and fixed bore and stroke) the loss due to the heat transfer effect correlates with a Reynolds number based on average piston velocity and diameter and average density. Because the gas at a given volume is hotter than the wall during compression and colder during expansion, the heat transfer cause the P-V diagram to enclose a negative area (work loss). It is interesting to note that the loss would be zero if the heat transfer were perfect (i.e., zero ΔT) so the gas remained at wall temperature. The loss would also be zero if the heat transfer were zero, as normally assumed. The loss must be a maximum at some point between. Preliminary data does indeed show a maximum loss condition. Further work is needed to evaluate this loss mechanism in the cases with flow as in fractical expanders.

Instrumentation and Control, Group 3

Chairman R. Louttit

BNL

The following summaries as prepared by the participants are submitted.



CONTROL DIAGRAM
LASL J Dean 6/80

Fermilab Satellite Refrigerator Control System

J. C. Gannon

Fermilab

The following is an outline of the Fermilab control systems:

I. Present Hardware and Software

1. B12 Stand-alone Test Facility
2. Multibus Based Microprocessor for Final System
3. Actuators
4. Transducers

Multibus Computer System

I. Eight Slots (Expandable to 12)

1. Microcomputer
2. Memory Expansion
3. 32-Channel MADC
4. 32-Channel MADC
5. Actuator Controller (8 Channel)
6. Actuator Controller (8 Channel)
7. Digital Input/Output Board
8. Resistor Temperature Monitor Board

II. PDP-11 for System Debug and Start-Up

1. Graphics
2. Data Logging
3. Available Locally

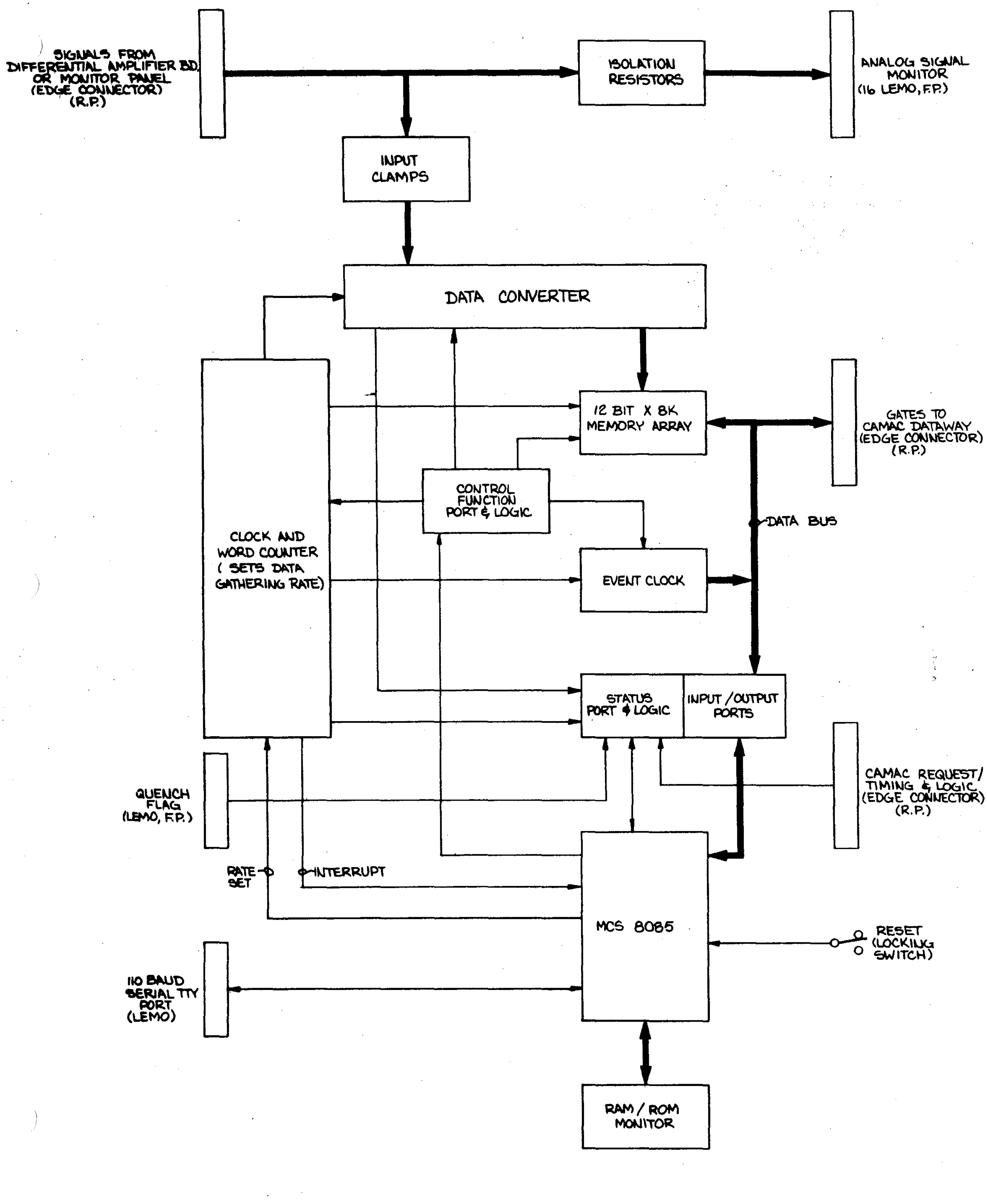
Spectrographic Nitrogen Detector

R. J. Walker

Fermilab

This device is used to detect a low level of nitrogen contamination in a stream of helium gas. The system operates on the principle of detecting the characteristic spectral emission lines of gaseous nitrogen. The stream of helium gas is fed through a transparent cell in which the gas is excited to the point of light emission. The next step is to analyze the light into its component wavelength and transmit to the detector only a narrow band of wavelengths. The choice of this wavelength determines which substance the system responds to. The wavelength analysis is accomplished with a grating monochromator The next step is to detect an intensity level (basically a photometer). In this case a photomultiplier was used. The combination of the high resolution of the grating monochromator and the high sensitivity of the photomultiplier make it possible to detect low levels of a contaminant while ignoring a large concentration of the pure gas and its characteristic emission lines.

A working model of the system has been built to test the principle, to get an idea of the sensitivity available, and to determine experimentally the optimum wavelength to use. The system was set up with a contamination of 50 parts per million by volume of nitrogen gas in a stream of ultrapure helium.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DATA CONVERTER
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MEMORY ARRAY
GATES TO
CAMAC DATAWAY
(EDGE CONNECTOR)
(R.P.)
CONTROL
FUNCTION
PORT & LOGIC
DATA BUS
CLOCK AND
WORD COUNTER
(SETS DATA
GATHERING RATE)
EVENT CLOCK
STATUS
PORT & LOGIC
INPUT / OUTPUT
PORTS
QUENCH
FLAG
(LEMO, F.P.)
CAMAC REQUEST/
TIMING & LOGIC
(EDGE CONNECTOR)
(R.P.)
RATE
SET
INTERRUPT
MCS 8085
RESET
(LOCKING
SWITCH)
110 BAUD
SERIAL TTY
PORT
(LEMO)
RAM / ROM
MONITOR

II. Requirements for a Cryogenic Control System

*Simplicity

*Continuous Service

*Complete

*Schedule

*Easily Interfaced by Operator

*Ample Facilities

*Minimize Manpower Requirements

*Proven System - Not "State of the Art"

*Flexible

III. Characteristics of an Industrial Process Control Computer

*Buy "off-the-shelf" a complete proven debugged system for industrial process control and monitoring.

*Pre-programmed process functions that user configures to his requirements.

*Simple "fill-in-the-blanks" language/English.

*No need to write or debug programs for system to get on line.

*If needed, easily added special programs for calculating heat balances, logging, etc.

*Software well documented, fully supported by supplier - the result of many iterations.

THE USE OF SUPERFLUID HELIUM AS A COOLANT FOR SUPERCONDUCTING ACCELERATOR MAGNETS*

Superfluid helium has been used on an experimental basis as a coolant for superconducting coils since the mid 1960's. In early tests the helium was used at the equilibrium vapor pressure, 15 to 30 mm Hg and the performance of most coils tested in this fashion was no better than at 4.2K in pool boiling helium. This result was rather surprising because the superconductor's critical current increases as the temperature decreases and the thermal conductivity of superfluid helium is much greater than that of helium at 4.2K.

In the early 1970's Claudet of the Centre d'Etudes Nucleaires Grenoble observed that superfluid helium could remove more heat from a surface if the pressure was elevated and suggested pressurized helium at 1.8K, where the heat transfer is greatest, as a coolant for superconducting magnets.

The Centre d'Etudes Nucleaires Saclay and the Lawrence Berkeley Laboratory began the development of 1.8K, 1 atm, test facilities in 1978 and, beginning in 1979, tested model accelerator dipoles in superfluid helium at temperatures down to 1.7K. The results of these tests showing an improvement in maximum current, and reduced training are summarized in Tables I and II. The short sample critical current at 1.8K was not reached in either case, most likely because the increased stresses in the coil limited performance.

More recently Fermilab tested a full scale doubler dipole at 2.17K in a modified test cryostat. The results of this test are given below.

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*Summary by editor.

TOWARDS TESTING AN ENERGY SAVER DIPOLE IN SUPERFLUID

M. Kuchnir

Fermilab

Two tests toward cooling an Energy Saver collared coil to superfluid He temperature were described. The concept as shown in the following figure of surrounding this dipole and parts of its surrounding liquid He by an adiabatic wall and cooling them by pumping on a He pot located in its bore permitted recovery from a quench to 2.17K in 70 minutes (30 minutes being typical dewar refill time for the system). Interesting observations about convection cooling and the propagation of a superfluid front were made. Cooling to sub-lambda temperatures have been prevented by superfluid heat-piping through gaps in the adiabatic wall; steps are being taken to correct this situation. So far the heat generated by the coil (TA-309) when ramped at 94A/sec to a quench resulted in the following above lambda quench history:

Temperature Before Start of Ramp	Quench Current	Comment
4.2K	5040A	After a short training sequence warmed to room temperature.
2.2K at top, 2.4K at bottom	5530A	First test.
4.2K	5060A	First test. Warmed to room temperature.
2.160K	5450A	Second test.
2.154K	5640A	Second test.
4.2K	5100A	Second test.

Agenda for Working Group 4 "Cryogenic Systems"

Chairman: C. Rode, FNAL

Session A (Monday, June 16, 10:30 - 12:30)

Distribution Systems

Transfer Line Designs, Fabrication, Installation
Heat Leaks
Superinsulation

Presentations by:

W. J. Schneider: ISABELLE Transfer Lines (Attachment I)
R. Fast: Superinsulation Tests Between 77 and 4K
C. H. Rode: Tevatron Transfer Line Design & Tests

We reviewed both the BNL and Fermi transfer line designs; both labs agree on the need for using shielded lines.

ISABELLE which has a central refrigerator, needs very large diameter lines, inside pipes, of 3, 4 and 6 in. They feel it is more economical to have separate supply and return lines. The Tevatron, on the other hand, uses a smaller 1 1/2-in. pipe as less than 10% of the magnet flow is transported in the cryogenic state.

BNL is using a upper limit of .05 W/ft for the design heat load of the liquid He pipe. The smaller Fermilab line was measured at 0.01 W/ft for the He pipe and 0.2 W/ft for the shield. It should be noted that both are avoiding 2-phase fluids in their lines.

We discussed heat fluxes in superinsulation for large systems and concluded that good design numbers were:

300 to 77K 0.1 W/ft for 1 in. at 60 layers/in.
77 to 4K 0.001 W/ft

It appears that 0.001 W/ft can be achieved with approximately 20 layers/in. or with high-emissivity surfaces.

BNL is also looking into invar and a flexible CERN-type line.

compressors stated that they needed full-flow, cryogenic pre-purification and provided data to support this. Dry compressors put out ring dust while wet compressors may break down the oil. The people with new compressors such as screws felt they didn't need it. It was also felt that turbines are much more sensitive to contamination than reciprocating expanders and in turn soft seat reciprocating expanders are more sensitive than hard seats which grind up contamination. (Editor's note: These same comments were made in the Compressor Group.)

Cryogenic Distribution System for ISABELLE

W. Schneider, BNL

The ISABELLE refrigeration system utilizes compressed liquid helium to supply refrigeration to approximately 1,100 superconducting magnets. These magnets steer the proton beams of the accelerator and are arranged into two interlocking rings. The cryogenic distribution system that is used to transfer the helium coolant from the central refrigerator to the superconducting magnets makes up a substantial portion (34%) of the total heat load, the pressure drop (61%), and the cost (26%), estimated for the overall cryogenic system. The piping system has been designed to minimize the heat input into the refrigeration system because of the high cost per watt of installed capacity. The transfer lines for ISABELLE are expected to be shielded single-vacuum enclosed lines of 7.5, 10 and 15 cm inner diameter. Heat leak into these lines is expected to be less than 0.15 W/m including expansion joints, anchors and supports. Installation of these lines into the magnet enclosure is anticipated to be accomplished by using a transporter system specifically designed to carry and install the piping and then employing automatic welding techniques.

superconducting level gauge. Liquid helium will be transferred from the storage dewar to magnet cryostats. The flow of this liquid will be regulated by an automatic valve in the supply line which will be controlled by signals from a superconducting level gauge in the magnet cryostats. The helium gas from the magnet cryostats is returned to the Model 1430.

Electric Power Applications of Superconductors

Joseph L. Smith, Jr.

MIT

The three major electric power applications of superconductors are in: 1) superconducting power transmission cables, 2) superconducting energy storage magnets for peaking power, and 3) superconducting rotating machines. Only two superconducting cable projects are now active: AC cables at BNL and DC cables at LASL. Superconducting magnets are being studied at the University of Wisconsin and LASL for peak power on a 24-h cycle and LASL is building a 30-MJ prototype energy storage magnet that will be used to stabilize the power system in the northwest against short time power fluctuations and power surges. Superconducting electric machines for ship drives are being studied at NSRDC Annapolis and prototype machines are being built under contract by Air Research and General Electric. Prototypes of large synchronous generators with superconducting windings are being constructed at MIT, Westinghouse, and General Electric.

Refrigeration problems of superconducting cables are unique because the refrigeration load is distributed along the great length of the cable. The large surface to volume ratio of the cable makes the cryogenic isolation and thermal insulation critical. The large length to diameter ratio of the cable causes complex flow transients which are driven by and coupled to the thermal transients resulting from electrical or mechanical disturbances of normal cable operation. The refrigerator must be normal at ambient temperature because AC loss would be too high in a superconducting or cryogenic winding. The machines must have external iron to contain the flux within the machine. The superconducting winding may be stationary or rotating. The stationary field is simpler but full power must be transferred from the motor by sliding contacts. Ship-drive machines have used stationary field windings while power station generators have used rotating superconductors because sliding contacts are not practical at GW power levels. The simplest superconducting machine is fully compensated so that the reaction from the power winding is balanced by currents in a normal compensating winding. Thus the superconductor sees no reaction force or field change due to the energy conversion in the machine. The field winding has simple DC magnet duty. Homopolar machines being developed for ship drives are fully compensated. The AC machines being developed for power stations have transient compensation by induction of eddy currents in a normally conducting shield that surrounds the superconductor and rotates as part of the rotor.

The homopolar machines for ship drives have stationary field windings and a drum type rotating power winding. The machines are fully compensated by the load currents in the stationary current return (compensating) drum. The major problem is not with the superconductors but rather with the sliding contacts (liquid sodium) that carry current to and from the rotor.

Power station generators have a complex rotating field winding with transient compensation by the eddy current shield (on the rotor) between

Helium Refrigeration Requirement for the Large Coil and Future Fusion Programs

T. L. Ryan

ORNL

The Large Coil Program (LCP) at Oak Ridge National Laboratory (ORNL) has as its goal the design, construction, and testing of six 8T 2.6 x 3.5 m^2 superconducting magnets which are prototypical of larger 10 to 12T, $5x6^2$ magnets for toroidal field coils in Tokamak fusion reactors. The six coils will be tested in the Large Coil Test Facility (LCTF) at ORNL. Each of the six 8T coils is unique. Three of the coils are pool-boiling cooled NbTi two are forced-flow cooled NbTi; and one of the coils is force-cooled Nb_3Sn. The suppliers are:

Supplier	Method of Cooling	Superconductor
(USA) General Dynamics	Pool Boiling	NbTi
(USA) General Electric	Pool Boiling	NbTi
(USA) Westinghouse	Forced Flow	Nb_3Sn
(Germany) Euratom	Forced Flow	NbTi
(Switzerland) SIN	Forced Flow	NbTi
(Japan) JAERI	Pool Boiling	NbTi

The total requirements of the different designs greatly increased the complexity of the cryogenic system for the LCTF. The system shown in Fig. 1 uses the refrigerator compressors to supply supercritical

Several interesting Tokamak Reactors have been proposed. The 10-12T "D" magnets for these designs will have a bore height of about 10 m and bore width of about 8 m. These reactors will require 45 to 90 kW of refrigeration at 4.4K and 300-600 ℓ/h of liquefaction at 4.4K for lead cooling.

The poloidal and toroidal field magnets may be forced-flow supercritical cooled, pool-boiling cooled, forced-flow 2-phase cooled, superfluid-helium cooled, or some mix of these methods. For example, a reactor might use forced-flow cooling for the horizontal, poloidal-field coils and pool boiling for the toroidal-field coils.

One goal of the large coil program is to evaluate the performance of pool boiling versus force cooled large superconducting magnets. Tests such as those to be performed in the LCP, further development in superconductor technology, and cost considerations will determine the final choices for reactor magnet designs.

The Efficiency of a Miniature Helium Expansion Turbine

H. Sixsmith

A miniature helium expansion turbine was developed during the years 1959 through 1963 at the National Bureau of Standards, at Boulder, Colorado. The diameter of the rotor is 5/16" and the design speed at 30K inlet temperature is 10,000 rps. At this speed the blade tip velocity is 800 ft/sec. The bearings are ambient temperature gas lubricated, externally pressurized and provided with pneumatic phase shift cavity stabilizers. The cavity stabilizers generate a damping force against any oscillatory motion of the shaft. The rotor of the turbine is supported on an extension of the shaft which projects into the cold region of the turbine. The shaft extension is surrounded by a grooved labyrinth which acts as a seal. Provision is made for equalizing the pressures at the warm and cold ends of the labyrinth so that the flow of gas through the clearance space can be reduced to a negligible value.

The turbine is of the mixed-flow type with a radial-flow nozzle ring and a radial-to-axial flow rotor. The rotor discharges into a conical diffuser with a semi-angle of 3^{o}. There are twelve complete blades and twelve partial blades. The blades are designed so that at the design speed the velocity of the gas leaving the rotor is one half the peripheral velocity of the rotor. The diffuser acts as a re-compressor converting most of the kinetic energy in the gas leaving

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FERMILAB CRYOGENIC WORKSHOP AGENDA

Monday, June 16

8:00-9:00	- Registration
9:00-9:10	- Welcome - L. M. Lederman
9:10-9:45	- Isabelle Refrigerator System - D. Brown
9:45-10:20	- Energy Saver Refrigerator System - C. Rode
10:20-10:40	- Coffee - (lounge)
10:40-12:30	- Working Groups
12:30-2:00	- Lunch
2:00-5:30	- Working Groups
6:30-7:30	- Cocktails
7:30-----	- Dinner

Tuesday, June 17

9:00-10:30	- Working Groups
10:30-12:30	- Tour
1:30-3:10	- Other Superconducting Programs (20 minutes)
	Electrical Power Applications - Joe Smith
	LCP and MHD - T. L. Ryan
	Topic to be Announced - H. Sixsmith
	HEP - W. B. Fowler
3:10-3:30	- Coffee - (lounge)
3:30-4:30	- Working Group Chairman Report

Following is a list of Technical Notes available at the Fermilab Cryogenic Workshop held June 16-17, 1980. Copies may be requested from the author.

"A Report on the Design of the Fermi National Accelerator Laboratory Superconducting Accelerator", excerpt on refrigeration, May 1979. Request from the Energy Saver Division, Fermilab.

"Operation of a Superconducting Beam Line at Fermilab", H. Haggerty, K. Krempetz and U. Patel, Fermilab.

"An Analysis of the Cooldown of the Central Liquefier", Henry Barton, Fermilab, June 1980, TM-971.

"Central: A Computer Program to do Performance Calculations for a Helium Liquefier", Henry Barton, Fermilab, May 1980, TM-967.

"Energy Doubler Satellite Refrigerator Magnet Cooling System", C. Rode, et. al., Fermilab.

"Investigation of Means to Increase Refrigeration Capacity of the CHL/Satellite Refrigeration System of the Fermilab Energy Doubler", prepared by Cryogenic Consultants, Inc., August 1979, TM-898. Request from the Energy Saver Division, Fermilab.

"Production and Use of High Grade Silicon Diode Temperature Sensors", J. Sondericker, BNL Technical Note 194, June 1980.

"A Very High Accuracy Cryogenic Digital Thermometer", J. Sondericker, BNL Technical Note 197, June 1980.

"Beam Tube Heat Shield and Superinsulation: Heat Transfer, Stresses, and Deformations", R. P. Shutt, BNL Technical Note 52, August 1977.

"Some Thoughts on Superinsulation", R. P. Shutt, BNL Technical Note 21, September 1976.

"Cryogenic Refrigeration Requirements for ISABELLE", D. Brown, BNL Technical Note 83, November 1978.

"Buffers to Prevent Thermal Shock During Cooldown or Warmup of Shock-Sensitive Components", R. P. Shutt, BNL Technical Note 81, November 1978.

"High and Medium Efficiency Fine Glass Fibers Filtration Media", Y. Kajiyama, LBL Engineering Note, March 1976.

"Cryopump Operations and Reliability", R. Byrns, LBL Engineering Note, April 1974.

"Accident with Swagelock Cap", R. Byrns, LBL Engineering Note, March 1964.

"ESCAR Refrigeration System", R. Byrns, BLB Engineering Note, May 1976. (Temperature-Entropy Chart for Helium 4)

"Main Ring Helium Line Configuration and Sizing", W. Pope/R. Byrns, LBL Engineering Note, May 1976.

"Compressor Performance", E. Hoyer/R. Byrns, LBL Engineering Note, July 1977/February 1978.

"Oil Removal System Design", R. Byrns, LBL Engineering Note, February 1976.

"Cost of Gases used at UCRL", R. Byrns, UCRL Engineering Note, July 1956.

"Cryogenic Heat Lead Estimates", W. Pope/R. Byrns, LBL Engineering Note, May 1976.

"Helium Refrigerator Cross-Connect Study", R. Byrns, LBL Engineering Note, August 1973.

"Pressure History", R. Byrns, UCRL Engineering Note, September 1972.

"ESCAR Helium Refrigerator Facility", T. Elioff/M. Green/R. Byrns, LBL Engineering Note, July 1974.

"Oil Removal System Notes from Ingersoll-Rand and Sullair Corp.", R. Byrns, LBL Engineering Note, March 1976.

"TFTR Neutral Beam Test Facility Cryopanel Helium Refrigerator", R. Byrns, LBL Specification, May 1977.

"Cryopump Reliability", R. Byrns, LBL Engineering Note, November 1973.

"Pressure Drop Design Data", R. Byrns, LBL Engineering Note, September 1975.

"72-In. Bubble Chamber Vent System Aerosol Removal", R. Byrns, UCRL Engineering Note, November 1960.

"Mechanical Engineering - Magnets, Solenoids, Coils, High Field Magnet Development, Helium Refrigeration/Liquefier", R. Warren/ R. Byrns, LBL Specification, March 1979.

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