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HELIUM REFRIGERATION SYSTEM FOR BNL COLLIDING BEAM ACCELERATOR

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Summary

A Helium Refrigeration System which will supply the cooling required for the Colliding Beam Accelerator at Brookhaven National Laboratory is under construction. Testing of the compressor system is scheduled for late 1983 and will be followed by refrigerator acceptance tests in 1984. The refrigerator has a design capacity of 24.8 kW at a temperature level near 4K while simultaneously producing 55 kW for heat shield loads at 55K. When completed, the helium refrigerator will be the world's largest. Twenty-five oil-injected screw compressors with an installed total of 23,250 horsepower will supply the gas required. One of the unique features of the cycle is the application of three centrifugal compressors used at liquid helium temperature to produce the low temperatures (2.5K) and high flow rates (4154 g/s) required for this service.

Discussion

The block diagram of Figure 1 shows the major components in the CBA Refrigeration System. A single refrigerator cools the entire plant. The load consists of both accelerators in the tunnel plus all the other required equipment at low temperature. The flow schematic for the Main Refrigerator and the Subcooler Circulation System is shown in Figure 2. Some of the calculated values for this cycle are shown in Figure 3. The calculated state points for the cycle are given in Figure 4. The major components of the Main Compressor System and the Gas Management and Purification Equipment are shown in the block diagram of Figure 5. The design capacity of the refrigerator is 1.5 times the expected heat input and pressure drop from the load. This will permit each of the 1084 magnets in CBA to be maintained below 3.8K, the design operating temperature.

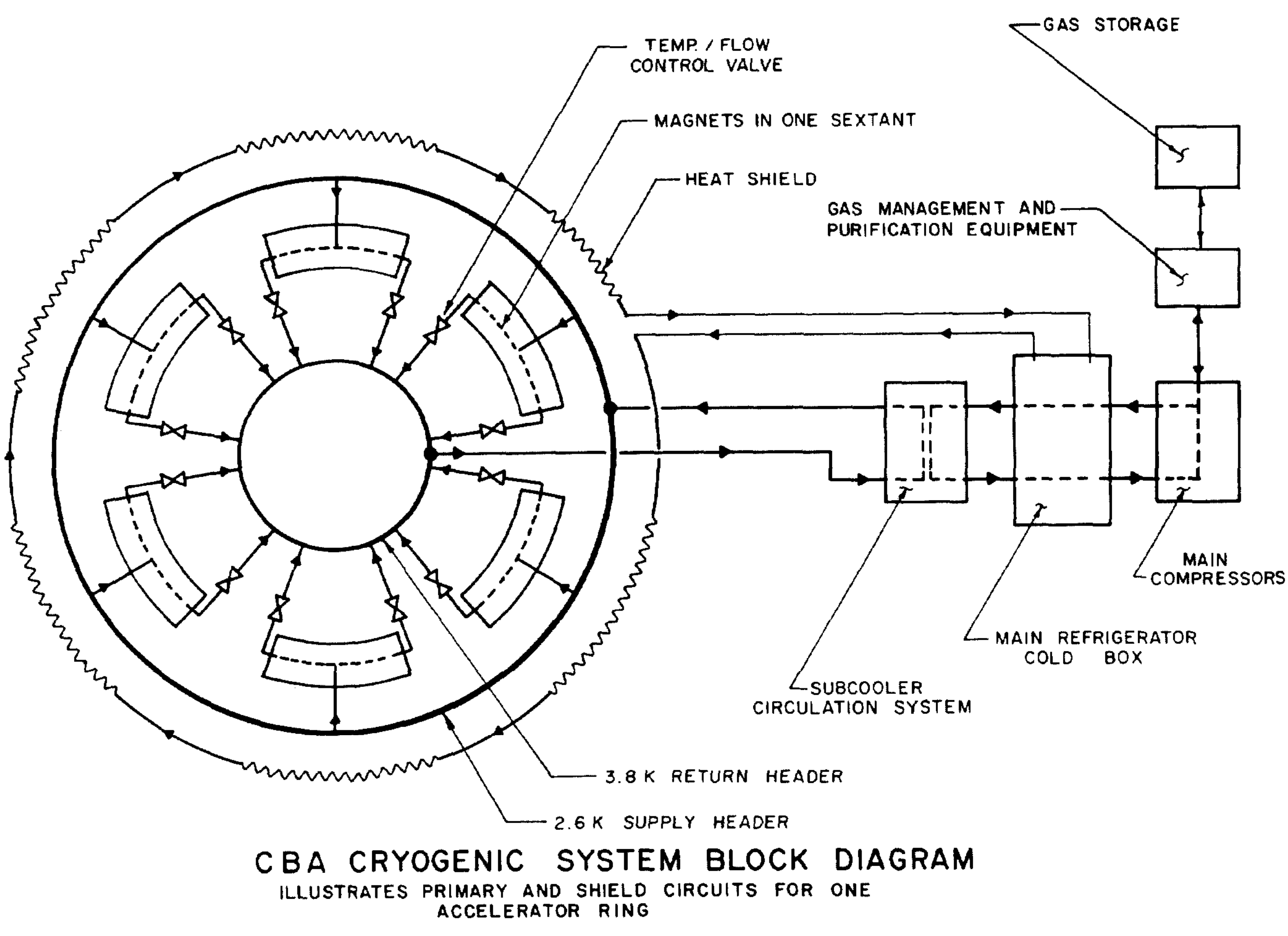

Figure 1

*Work performed under the auspices of the U.S. Department of Energy.

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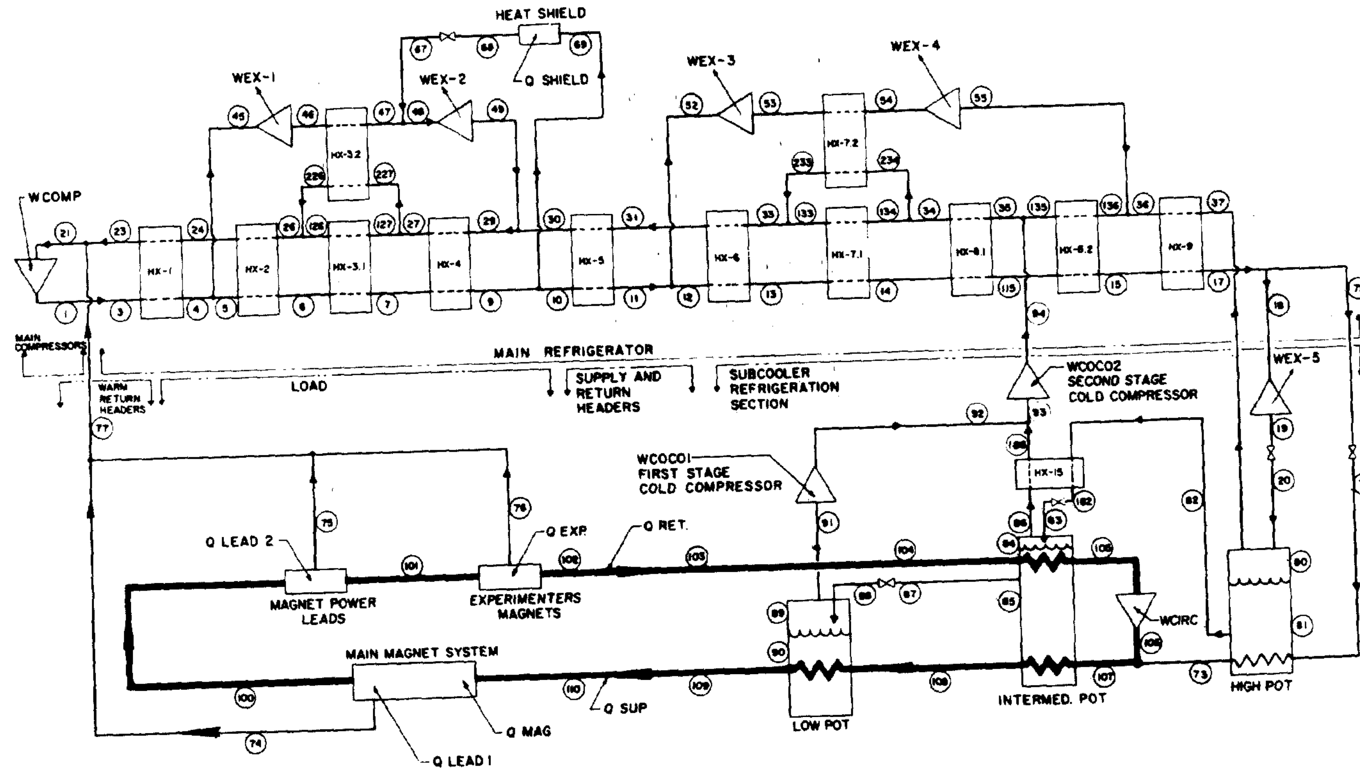


CBA HELIUM REFRIGERATOR CYCLE FLOW SCHEMATIC

Figure 2

SYSTEM DESIGN STEADY-STATE LOAD REQUIREMENTS

REFRIGERATION REQUIRED-WATTS

QMAG	QLEAD1	QLEAD2	QSUP	QRET	QEXP	QSHLD
7650.	200.	2300.	1500.	2000.	0.	55000.

MASS FLOW REQUIRED-GM/SEC

F74	F75	F76
6.	44.	50.

OTHER ESTIMATED REFRIGERATION LOADS-WATTS

QHX1	QHX2	QHX3	QHX4	QHX5	QHX6	QHX7	QHX8	QHX9	QHX10	QHX11	QHX12
947.0	3240.0	2663.0	1880.0	240.0	410.0	600.0	520.0	180.0	340.0	290.0	290.0

EXPANDER/COMPRESSOR PARAMETERS

	MAIN COMPR.	COLD COMPR. 1	COLD COMPR. 2	CIRC. COMPR.	EXPANDER 1	EXPANDER 2	EXPANDER 3	EXPANDER 4	EXPANDER 5
ADIABATIC EFFICIENCY		.680	.670	.580	.810	.820	.800	.780	.760
ISOTHERMAL EFFICIENCY	.60								
INLET PRESSURE-ATM	1.050	.095	.340	4.150	16.227	8.860	15.579	7.922	15.494
OUTLET PRESSURE-ATM	17.250	.350	1.389	5.450	9.000	1.301	8.000	1.423	2.500
INLET TEMPERATURE-K	302.00	2.46	4.61	3.47	185.00	69.37	25.00	12.38	6.29
OUTLET TEMPERATURE-K	305.00	4.83	9.64	3.79	153.64	38.93	20.19	7.10	5.14
FLOW RATE-GM/SEC	4212.2	333.2	982.4	4054.0	658.3	1014.2	1729.0	1729.0	1368.9
WORK-WATTS	12427821.	3933.	24764.	6213.	-108816.	-162034.	-42130.	-36736.	-10489.
WORK-HP	16659.	5.	33.	8.	-146.	-217.	-56.	-49.	-14.

HEAT EXCHANGER PARAMETERS

	HX1	HX2	HX3.1	HX3.2	HX4	HX5	HX6	HX7.1	HX7.2	HX8.1	HX8.2	HX9	HX15
EFFECTIVENESS	.976	.942	.978	.978	.964	.939	.973	.986	.986	.699	.954	.939	.923
AU(KW/K)	607.09	161.00	523.50	95.93	238.09	165.66	53.37	138.23	152.71	18.52	54.22	8.46	20.19
NTU	28.43	8.71	29.05	28.69	12.63	10.23	6.26	17.67	17.59	1.75	5.64	3.00	5.16

LOAD SUMMARY

	PRIMARY LOAD		SECONDARY LOAD	
	SUPPLY	RETURN	SUPPLY	RETURN
FLOW RATE-GM/SEC	4153.98	4053.98	355.91	355.91
TEMPERATURE-K	2.59	4.19	40.00	69.35
PRESSURE-ATM	5.35	4.20	15.67	9.67
DENSITY-GM/CC	.154	.139	.01842	.00668
ENTHALPY-J/GM	7.32	10.63	222.00	376.53

CALCULATED PERFORMANCE OF A HELIUM REFRIGERATOR WHICH UTILIZES 5 EXPANDERS AND 3 COLD COMPRESSORS. DELIVERY OF THE REFRIGERANT IS IN THE FORM OF COMPRESSED LIQUID HELIUM WHICH IS CIRCULATED BY ONE OF THE THREE COMPRESSORS IN THE CYCLE.

Figure 3

FLUID PROPERTIES AND FLOW RATES

PRESSURE(ATM), TEMPERATURE(K), ENTHALPY(J/GM) AND FLOW RATE(GM/SEC)

POINT	PRESS.	TEMP.	ENTHAL.	FLOW
1	17.250	305.00	1604.33	4212.15
3	16.400	305.00	1604.04	4212.15
4	16.278	185.00	980.61	4212.15
5	16.278	185.00	980.61	3553.88
6	16.181	153.64	817.52	3553.88
7	15.999	69.37	377.82	3553.88
9	15.676	40.00	222.00	3553.88
10	15.666	40.00	222.00	3197.97
11	15.636	25.00	139.41	3197.97
12	15.636	25.00	139.41	1468.94
13	15.606	20.19	111.54	1468.94
14	15.575	12.38	62.75	1468.94
115	15.553	10.45	48.84	1468.94
15	15.543	7.30	28.27	1468.94
17	15.533	6.28	23.59	1468.94
18	15.494	6.29	23.59	1368.94
19	2.500	5.14	15.93	1368.94
20	1.434	4.61	15.93	1368.94

LIQUID FRACTION AT PT. 20 IS .778

POINT	PRESS.	TEMP.	ENTHAL.	FLOW
80	1.424	4.61	29.54	386.50
81	1.424	4.61	11.99	1061.35
82	1.424	4.61	11.99	982.44
182	1.414	3.47	7.07	982.44
83	.350	3.27	7.07	982.44

LIQUID FRACTION AT PT. 83 IS .953

POINT	PRESS.	TEMP.	ENTHAL.	FLOW
84	.350	3.27	29.03	649.21
85	.350	3.27	5.99	936.41
86	.350	3.27	29.03	649.21
186	.340	4.49	36.47	649.21
87	.350	3.27	5.99	333.23
88	.100	2.49	5.99	333.23

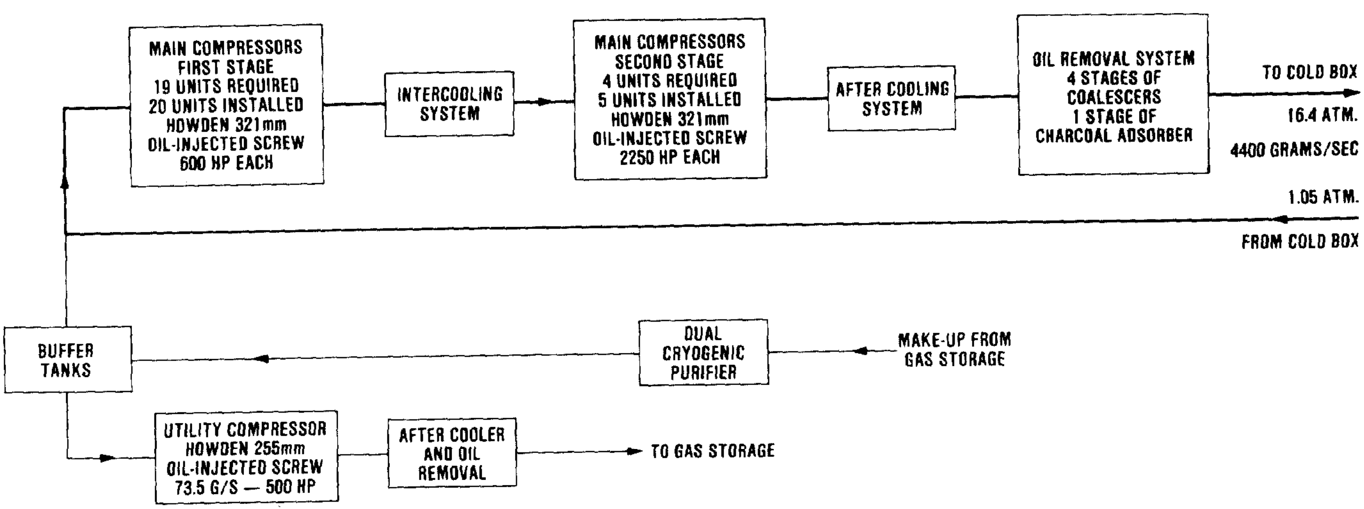
LIQUID FRACTION AT PT. 88 IS .913

POINT	PRESS.	TEMP.	ENTHAL.	FLOW
89	.100	2.49	26.63	333.23
90	.100	2.49	4.02	304.15
91	.095	2.46	26.53	333.23
92	.350	4.83	38.33	333.23
93	.340	4.61	37.10	982.44
94	1.389	9.64	62.31	982.44

POINT	PRESS.	TEMP.	ENTHAL.	FLOW
21	1.050	302.00	1583.34	4212.15
23	1.100	302.00	1583.34	4112.15
24	1.139	178.99	944.52	4112.15
26	1.166	151.69	802.78	4112.15
126	1.166	151.69	802.78	3468.61
127	1.243	64.90	351.89	3468.61
226	1.166	151.69	802.78	643.54
227	1.243	64.90	351.89	643.54
27	1.243	64.90	351.89	4112.15
29	1.294	38.93	216.76	4112.15
30	1.306	38.93	216.76	3097.97
31	1.318	22.60	131.43	3097.97
33	1.330	20.06	118.08	3097.97
133	1.330	20.06	118.08	1468.38
134	1.348	10.87	69.07	1468.38
233	1.330	20.06	118.08	1629.58
234	1.348	10.87	69.07	1629.58
34	1.348	10.87	69.07	3097.97
35	1.389	9.64	62.31	3097.97
135	1.389	9.64	62.31	2115.53
136	1.404	7.10	47.78	2115.53
36	1.404	7.10	47.78	386.50
37	1.411	4.60	29.54	386.50
100	4.550	3.80	9.57	4147.98
101	4.550	3.99	10.13	4103.98
102	4.550	3.99	10.13	4053.98
103	4.200	4.19	10.63	4053.98
104	4.200	4.19	10.63	4053.98
105	4.150	3.47	8.47	4053.98
106	5.450	3.79	10.01	4053.98
107	5.450	3.82	10.08	4153.98
108	5.400	3.37	8.91	4153.98
109	5.350	2.59	7.32	4153.98
110	5.000	2.90	7.68	4153.98

POINT	PRESS.	TEMP.	ENTHAL.	FLOW
45	16.227	185.00	980.61	658.27
46	9.000	153.64	815.31	658.27
47	8.904	69.37	376.53	658.27
48	8.860	69.37	376.53	1014.19
49	1.301	38.93	216.76	1014.19
52	15.579	25.00	139.41	1729.03
53	8.000	20.19	115.05	1729.03
54	7.922	12.38	69.03	1729.03
55	1.423	7.10	47.78	1729.03
67	8.904	69.37	376.53	355.91
68	9.666	69.35	376.53	355.91
69	15.666	40.00	222.00	355.91
71	15.494	6.29	23.59	100.00
72	5.550	6.34	23.59	100.00
73	5.450	4.71	13.14	100.00
74	4.975	3.35	8.63	6.00
75	4.550	3.80	9.57	44.00
76	4.550	3.99	10.13	50.00
77	1.050	302.00	1583.32	100.00

Figure 4



CBA COMPRESSOR SYSTEM BLOCK DIAGRAM

Figure 5