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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 53K. 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.

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CBA CRYOGENIC SYSTEM BLOCK DIAGRAM
ILLUSTRATES PRIMARY AND SHIELD CIRCUITS FOR ONE
ACCELERATOR RING

Figure 1

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CRA HELIUM REFRIGERATOR CYCLE FLOW SCHEMATIC

Figure 2

SYSTEM DESIGN STEADY-STATE LOAD REQUIREMENTS

REFRIGERATION REQUIRED-WATTS							MASS FLOW REQUIRED-GH/SEC				
Q MAG	Q LEAD1	Q LEAD2	Q SUP	Q RET	Q EXP	Q SHLD	FTS	FTS	FTS	FTS	
7850.	200.	2300.	1500.	2000.	0.	25000.	5.	44.	50.		
OTHER ESTIMATED REFRIGERATION LOADS-WATTS											
Q HK1	Q HK2	Q HK3	Q HK4	Q HK5	Q HK6	Q HK7	Q HK8	Q HK9	Q HK10	Q HK11	
347.0	3240.0	2863.0	1880.0	240.0	410.0	600.0	520.0	180.0	240.0	290.0	
347.0	3240.0	2863.0	1880.0	240.0	410.0	600.0	520.0	180.0	240.0	290.0	

EXPANDER/COMPRESSOR PARAMETERS										
	MAIN COMP.	COLD COMP. 1	COLD COMP. 2	CIRC. COMP.	EXPANDER 1	EXPANDER 2	EXPANDER 3	EXPANDER 4	EXPANDER 5	
ADIABATIC EFFICIENCY	.60	.320	.670	.580	.810	.820	.800	.780	.760	
ISOTHERMAL EFFICIENCY	1.250	.095	.340	4.150	18.227	9.880	15.578	7.922	15.484	
INLET PRESSURE-ATM	17.250	350	1.388	5.450	9.000	1.301	9.000	1.423	2.500	
OUTLET PRESSURE-ATM	302.00	2.46	4.61	3.47	189.00	88.37	29.00	12.58	6.29	
INLET TEMPERATURE-K	305.00	4.83	9.84	3.79	153.84	38.33	20.19	7.10	5.14	
OUTLET TEMPERATURE-K	4212.2	333.2	388.4	4094.0	958.3	1014.2	1729.0	1729.0	1388.8	
FLOW RATE-GH/SEC	1247881.	3333.	24784.	5213.	-108618.	-182034.	-42130.	-38736.	-10489.	
WORK-WATTS	1.8899.	5.	33.	9.	-146.	-217.	-36.	-49.	-14.	
WORK-MHP										

HEAT EXCHANGER PARAMETERS										
	HK1	HK2	HK3.1	HK3.2	HK4	HK5	HK6	HK7.1	HK7.2	HK8.1
EFFECTIVENESS	.978	.978	.978	.978	.978	.978	.978	.978	.978	.978
AUTOMATIC	507.09	161.00	523.50	95.93	238.08	89.88	53.37	138.23	152.71	18.52
NTU	28.43	8.71	29.05	29.68	12.53	10.23	5.28	17.57	17.58	1.78

LOAD SUMMARY											
	PRIMARY LOAD				SECONDARY LOAD						
	SUPPLY	RETURN	SUPPLY	RETURN	SUPPLY	RETURN	SUPPLY	RETURN			
FLOW RATE-GH/SEC	4153.98	4033.98	235.31	235.31	2.50	2.50	2.50	2.50			
TEMPERATURE-K	2.50	4.19	40.00	58.35	2.50	2.50	2.50	2.50			
PRESSURE-ATM	5.35	4.20	15.67	9.67	5.35	5.35	5.35	5.35			
DENSITY-GH/CC	154	139	31842	30888	154	154	154	154			
ENTHALPY-J/GH	7.32	10.83	222.00	378.53	7.32	7.32	7.32	7.32			

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/GH) AND FLOW RATE(GM/SEC)														
POINT	PRESS.	TEMP.	ENTHAL.	FLOW	POINT	PRESS.	TEMP.	ENTHAL.	FLOW	POINT	PRESS.	TEMP.	ENTHAL.	FLOW
1	17.250	308.00	1004.33	4212.15	21	1.250	302.00	1983.34	4212.15	45	18.227	185.00	380.61	898.27
2	16.400	302.00	1004.34	4212.15	23	1.100	302.00	1983.34	4212.15	46	8.000	153.84	815.31	898.27
3	16.470	180.00	980.61	4212.15	24	1.130	178.90	944.52	4212.15					
4	16.270	180.00	980.61	4212.15										
6	16.161	153.84	817.32	3803.80	26	1.100	151.00	802.70	4212.15					
					126	1.100	151.00	802.70	3480.61					
					127	1.243	84.80	381.80	3480.61					
					266	1.100	151.00	802.70	945.24					
					267	1.243	84.80	381.80	945.24					
					27	1.243	84.80	381.80	4212.15					
7	15.888	88.37	377.88	3803.80						47	8.804	88.37	378.53	898.27
9	15.876	48.00	282.00	3803.80	29	1.293	38.83	216.76	4212.15	48	8.800	88.37	378.53	1014.18
10	15.888	48.00	282.00	3187.87	30	1.308	38.83	216.76	3087.87	49	8.301	38.83	216.76	1014.18
11	15.838	25.00	130.41	1488.94	31	1.318	38.80	131.43	3087.87					
12	15.838	25.00	130.41	1488.94										
13	15.888	28.19	111.94	1488.94	33	1.330	20.06	110.08	3087.87	52	19.379	25.00	130.41	1729.03
					133	1.330	20.06	110.08	1488.94	53	8.000	25.19	115.06	1729.03
					134	1.340	10.87	88.07	1488.94					
					233	1.330	20.06	110.08	1629.58					
					234	1.340	10.87	88.07	3087.87					
14	15.878	12.38	82.75	1488.94	34	1.340	10.87	88.07	3087.87	54	7.888	12.38	82.03	1729.03
15	15.888	10.49	48.84	1488.94										
16	15.843	7.30	28.27	1488.94	36	1.388	9.84	82.31	3087.87	55	1.423	7.10	47.78	1729.03
					136	1.388	9.84	82.31	2115.53					
					137	1.411	7.10	47.78	2115.53					
					36	1.404	7.10	47.78	388.50					
					37	1.411	4.80	29.54	388.50					
										57	8.804	88.37	378.53	395.91
										58	9.688	88.35	378.53	395.91
										59	15.888	-0.00	222.00	395.91
60	1.424	4.61	28.34	388.50	100	4.950	3.80	9.57	4147.98	71	15.494	8.29	23.58	100.00
61	1.424	4.61	11.98	1081.25	101	4.950	3.88	10.13	4103.98	72	5.350	8.34	23.58	100.00
62	1.424	4.61	11.98	888.44	102	4.950	3.88	10.13	4053.98					
63	1.414	3.47	7.27	888.44						73	5.450	4.71	13.14	100.00
64	.388	3.27	7.07	888.44	103	4.200	4.19	10.63	4053.98					
LIQUID FRACTION AT PT. 63 IS .993					104	4.200	4.19	10.63	4053.98	74	4.875	3.35	8.63	8.00
65	.350	3.27	28.03	849.21	105	4.150	3.47	8.47	4053.98	75	4.250	3.80	9.57	44.00
66	.350	3.27	5.98	138.41	106	5.450	3.78	10.01	4053.98	76	4.250	3.98	10.13	50.00
67	.350	3.27	28.03	849.21						77	1.350	302.00	1983.32	100.00
68	.340	4.48	38.47	849.21	107	5.450	3.88	10.08	4153.98					
69	.350	3.27	5.98	333.23	108	5.400	3.37	8.31	4153.98					
LIQUID FRACTION AT PT. 88 IS .913					109	5.350	2.98	7.32	4153.98					
90	.100	2.48	28.63	333.23	110	5.000	2.80	7.88	4153.98					
91	.085	2.48	4.02	304.15										
92	.350	4.63	38.33	333.23										
93	.340	4.61	37.10	888.44										
94	1.388	9.84	82.31	588.44										

Figure 4

CBA COMPRESSOR SYSTEM BLOCK DIAGRAM

Figure 5

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