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Cold Vacuum Compressor for RHIC Helium Refrigerator

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Collider Accelerator Department

Brookhaven National Laboratory

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RHIC PROJECT

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INTRODUCTION

The RHIC 24.8 kilowatt refrigerator was originally designed for ISABELLE with the low pot, a liquid helium vessel in cold box 5, to be operated at 0.1 atm pressure for 2.49 K[1]. A four stage cold vacuum compressor was built to pump helium vapor from 0.095 to 1.4 atm.

The RHIC cryogenic system is designed for 4.6 K operating temperature with 0.92 atm pressure in the low pot. This report presents the latest requirement for the cold vacuum compressor.

HEAT LOAD BUDGET

The heat load budget, including 4.5 K refrigeration load, liquefaction load and 55 K shield load, is given in RHIC Design Manual.[2] The 4.5 K primary load are summarized in Table 1.

TABLE 1. HEAT LOAD BUDGET SUMMARY

MAGNET SYSTEM	2987	WATT
POWER LEAD	1855	WATT +
	48	G/S LIQUID
DISTRIBUTION SYSTEM	1020	WATT
DETECTORS	45	G/S LIQUID
TOTAL	5770	WATT +
	93	G/S LIQUID

The 55 K secondary heat load budget is 30 kilowatt. However 55 kilowatt is used in the process calculation because the secondary heat load does not have a large impact on the overall results.

PERFORMANCE OF THE REFRIGERATOR

Due to the change of temperature requirement and cooling scheme, the refrigeration cycle will be modified for RHIC as shown in Fig. 1.

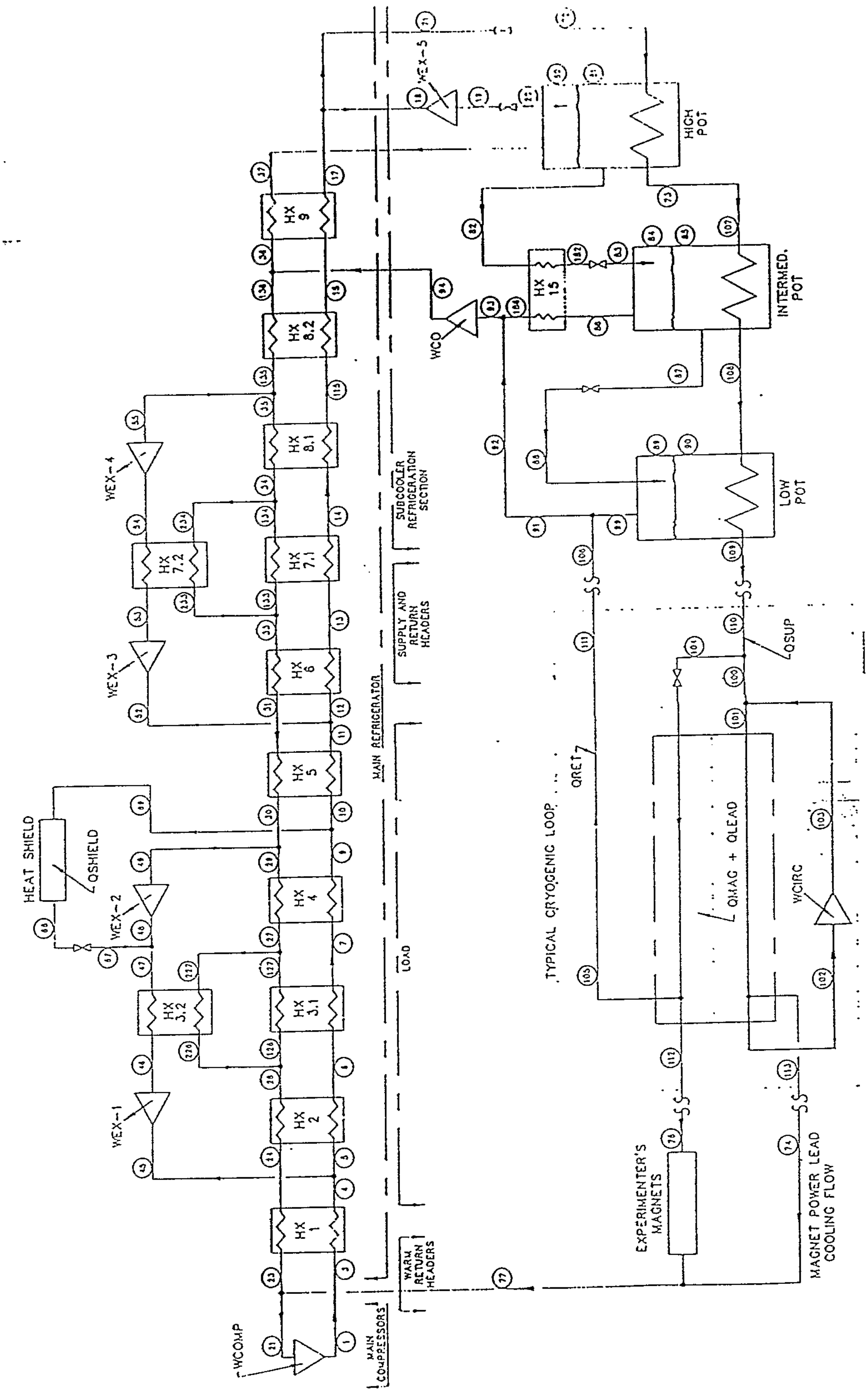

Fig. 1 Cycle schematic for the RHIC refrigerator

The process requirement is re-calculated from the updated heat load and a new baseline performance for the refrigerator is given in fig. 2.

PROGRAM RHIC

CALCULATE PERFORMANCE OF RHIC HELIUM REFRIGERATOR WHICH UTILIZES 5 EXPANDERS AND 1 COLD VACUUM COMPRESSOR. CIRCULATING COMPRESSORS LOCATED IN THE RINGS ARE USED TO CIRCULATE THE COLD HELIUM THROUGH THE MAGNETS.

SUMMARY OF SYSTEM PARAMETERS

REFRIGERATION-WATTS					MASS FLOW-G/S	
QMAG	QLEAD	QSUP	QRET	QSHLD	F74	F76
2875.	1855.	800.	240.	55000.	48.	45.

ESTIMATED HEAT LEAKS IN THE HEAT EXCHANGERS - WATTS

HX1	HX2	HX3	HX4	HX5	HX6	HX7	HX8	HX9	H. POT	I. POT	L. POT
950.	3240.	2670.	1880.	240.	410.	600.	520.	180.	340.	290.	290.

HEAT EXCHANGER PARAMETERS

HEAT EXCHANGER	HIGH P FLOW G/S	LOW P FLOW G/S	CMAX/ CMIN	EFFECTIVENESS RATIO	REQUIRED AU KW/K	REQUIRED NTU	DESIGN AU KW/K
1.0	2486.4	2393.4	1.040	.977	317.0	25.51	684.0
2.0	1853.3	2393.4	1.274	.937	64.2	6.66	183.1
3.1	1853.3	1783.6	1.046	.979	240.6	25.96	533.8
3.2	633.2	609.9	1.046	.979	81.3	25.66	103.8
4.0	1853.3	2393.4	1.256	.978	114.2	11.60	280.4
5.0	1449.0	1356.0	1.128	.967	94.9	13.40	201.2
6.0	647.8	1356.0	1.799	.873	12.7	3.38	58.4
7.1	647.8	626.2	1.216	.944	26.6	7.96	127.8
7.2	801.1	729.7	1.216	.944	31.0	7.95	148.5
8.1	647.8	1356.0	1.689	.895	13.9	3.05	33.7
8.2	647.8	554.8	1.191	.947	14.0	4.68	61.8
9.0	647.8	187.8	1.484	.807	3.1	1.69	11.5

EXPANDER PARAMETERS

TURBINE	PIN ATM	POUT ATM	TIN K	TOUT K	FLOW G/S	ETA	WORK W
1.0	16.23	9.00	180.00	151.78	633.	.75	94317.
2.0	8.86	1.30	65.84	39.42	1037.	.75	143895.
3.0	15.58	8.00	25.00	20.73	801.	.70	17080.
4.0	7.92	1.41	12.45	7.50	801.	.70	15512.
5.0	15.49	2.50	5.03	4.98	259.	.50	1184.

COMPRESSOR PARAMETERS

COMP.	ISO-THER. EFF.	ADIA-BATIC EFF.	PIN ATM	POUT ATM	TIN K	TOUT K	FLOW G/S	WORK KW	WORK H.P.	IN VOL FL ACFM	IN DENSI. G/CC	PRES RATIO
MAIN	.50		1.05	17.25	302.0	305.0	2486.	8803.	11801.			
COLD		.60	.92	1.40	4.20	5.24	367.0	1.779	2.385	52.4	.0148	1.531
CIRCU.		.50	4.58	5.00	4.50	4.62	100.0	.063	.084		.136	

ONE CIRCULATING COMPRESSOR IS REQUIRED IN EACH OF THE 2. CRYOGENIC LOOPS

LOAD SUMMARY

	PRIMARY LOAD		SECONDARY LOAD	
	SUPPLY	RETURN	SUPPLY	RETURN
FLOW RATE-G/S	388.77	295.77	404.32	404.32
PRESSURE-ATM	5.01	.93	15.67	9.67
TEMPERATURE-K	4.19	4.23	40.00	65.81
ENTHALPY-J/G	11.02	30.95	222.00	358.03

Fig. 2 Base line performance requirements for the RHIC refrigerator

PERFORMANCE REQUIREMENTS FOR THE COLD VACUUM COMPRESSOR

From fig. 2, the nominal design conditions for the cold vacuum compressor are given in Table 2.

Table 2. The nominal design condition for the cold vacuum compressor

Adiabatic Efficiency (%)	0.60
Flow Rate (gm/sec)	367
Input Work (watts)	1747
Inlet	
Pressure (atm)	0.92
Temperature (K)	4.20
Density (gm/cc)	0.0149
Volume flow (liter/sec)	24.59
Outlet	
Pressure (atm)	1.40
Temperature (K)	5.22
Density (gm/cc)	0.0173
Pressure ratio	1.52

For either reduced operating temperature or as a safety margin for the pressure drop in the vapor return line, it is necessary to have lower suction pressure in the compressor as shown in Table 3.

Table 3. The low suction pressure conditions for the cold vacuum compressor

Adiabatic Efficiency (%)	0.60	0.60
Flow Rate (gm/sec)	367	367
Input Work (watts)	2312	3279
Inlet		
Pressure (atm)	0.80	0.65
Temperature (K)	4.00	3.80
Density (gm/cc)	0.0135	0.0110
Volume flow (liter/sec)	27.28	33.28
Outlet		
Pressure (atm)	1.40	1.40
Temperature (K)	5.35	5.69
Density (gm/cc)	0.0165	0.0148
Pressure ratio	1.75	2.15

For extra refrigeration capacity, the high flow conditions corresponding to the above suction pressures are given in Table 4. The cold compressor, as specified in Table 4, will allow the RHIC refrigerator to be operated approximately twice the refrigeration capacity than budget. The 93 gm/sec liquefaction load is the same.

Table 4. The high flow conditions for the cold vacuum compressor

Adiabatic Efficiency (%)	0.60	0.60	0.60
Flow Rate (gm/sec)	600	570	500
Input Work (watts)	2875	3591	4467
Inlet			
Pressure (atm)	0.92	0.80	0.65
Temperature (K)	4.20	4.00	3.80
Density (gm/cc)	0.0149	0.0135	0.0110
Volume flow (liter/sec)	40.19	42.37	45.35
Outlet			
Pressure (atm)	1.40	1.40	1.40
Temperature (K)	5.22	5.35	5.69
Density (gm/cc)	0.0173	0.0165	0.0148
Pressure ratio	1.52	1.75	2.15

REFERENCES

1. D.P. Brown, A. P. Schlafke, K. C. Wu and R. W. Moore, Cycle Design for the ISABELLE Helium Refrigerator, in "Advances in Cryogenic Engineering", Vol.27, p509, Plenum Press, New York, 1982.

2. D. P. Brown, Table 3.1 Cryogenic System Heat Load Allowance, "RHIC Design Manual", BNL, 1992.