SNS* 2.1K COLD BOX TURN-DOWN STUDIES

F. Casagrande, P. Gurd, D. Hatfield, M. Howell, H. Strong, SNS Project, Oak Ridge National Laboratory (ORNL), TN 37831
D. Arenius, V. Ganni, P. Knudsen, J. Creel, Thomas Jefferson National Accelerator Facility (TJNAF) Newport News, VA, 23606

Abstract

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is nearing completion. The cold section of the Linac consists of 81 superconducting radio frequency cavities cooled to 2.1K by a 2400 watt cryogenic refrigeration system. The 2.1K cold box consists of four stages of centrifugal compressors with LN_2-cooled variable speed electric motors and magnetic bearings. The cryogenic system successfully supported the Linac beam commissioning at both 4.2K and 2.1K and has been fully operational since June 2005. This paper describes the control principles utilized and the experimental results obtained for the SNS cold compressors turn-down capability to about 30% of the design flow, and possible limitation of the frequency-dependent power factor of the cold compressor electric motors, which was measured for the first time during commissioning. These results helped to support the operation of the Linac over a very broad and stable cold compressor operating flow range (refrigeration capacity) and pressure. This in turn helped to optimise the cryogenic system operating parameters, minimizing the utilities and improving system reliability and availability.

INTRODUCTION

The SNS cryogenic system was designed to provide refrigeration capacities of 2.4KW at 2.1K, 8.3KW from 35K to 50K and 15g/s liquefaction for coupler cooling Figure 1 is a block diagram of the cryogenic system. For a detailed description of the system and the commissioning see Ref. [1] and the references thereto.

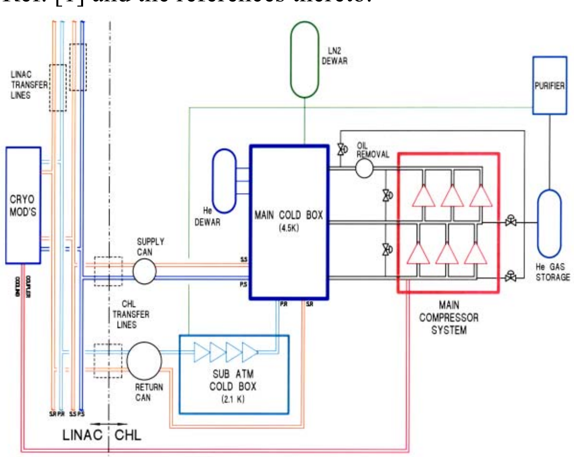

Figure 1: Cryogenic System Block diagram.

In the following sections the automatic sequence that controls the cold compressors' low flow will be introduced. The test results obtained for maximum and minimum capacity at 2.1K will be presented. The problem of the cold compressor motor power factor and how it affects the pump down will be discussed. Finally, the tests performed on the 1st and 2nd stage Main Warm compressors to determine volumetric and isothermal efficiencies by varying both built-in volume ratio and pressure ratios will be presented.

2.1K TURN DOWN

A set of automatic sequences have been developed to control the SNS Cryogenic System, [2]. After nominal flow (125g/s) is established through the cold compressors, the variable frequency drive set point is lowered on cold compressor four such that its speed is just above the low power factor point (see Power Factor section). Since the other three cold compressor frequency drives are set in ratio to cold compressor four, this slows all four cold compressors down. During this initial ramping, cold compressors three and four are set to just above the low power factor point or until the desired flow is attained. If it is necessary to ramp the flow down more, the sequence then compares the current pressure ratios on cold compressors one and two and throttles them until they are set just above the minimum power factor point or until the desired flow is achieved, see Figure 2.

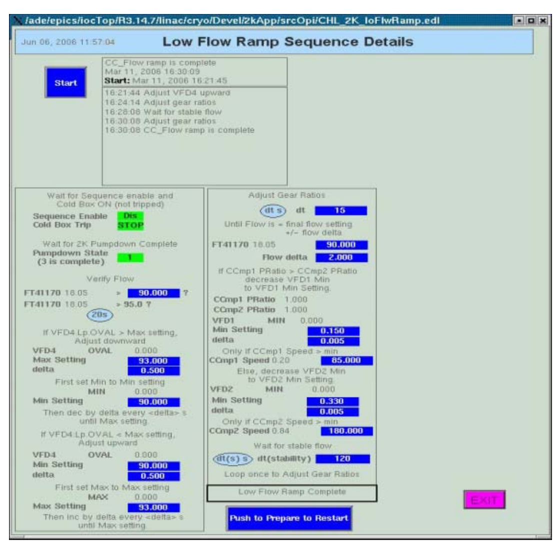

Figure 2: Low Flow Ramp Sequence Details.

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The main results obtained for stable operations are:

Minimum 2.1K Capacity
Cold Compressor Flow = 90 g/s
Shield load= 5.3 kW (60 g/s @37K-53K)
Excess liquefaction = 4.0 g/s
Max system pressure = 12.9 atm

Maximum 2.1K Capacity
Cold Compressor Flow = 140 g/s
Shield load= 5.3 kW (60 g/s @37K-53K)
Excess liquefaction = 0.0 g/s
Max system pressure = 17.0 atm

The following table provides the additional details of the input power, system maximum operating pressure and the over all efficiency of the system.

Table 1: System Operating Parameters and Carnot Work Summary

	Design Basis	Max Capacity	Nominal Capacity	Minimum Capacity
I st Stage compressors (KW)	608			
C1 (KW)		300	250	244
C3 (KW)		300	300	203
II nd Stage compressors (KW)	2074			
C4 (KW)		1456	1355	762
C5 (KW)		1456	1355	1154
Ln2 Usage (g/s)	120	200	180	150
Total Electric Input Power to Compressors (KW)	2682	3512	3260	2363
Ln2 Equivalent Power (@35% Carnot) (KW)	216	360	324	270
Total Input Power Equivalent (KW)	2898	3872	3584	2633
HP to cold Box (Atm)	16.8	17	16.5	12.9
MP cold Box out (Atm)	4	2.8	2.8	2.5
Cold box HP Flow (g/s)	1150	1077	1030	829
CC Flow (g/s)	**125**	**140**	**125**	**90**
Liquefaction Load (g/s)	15	4	4	4
Shield Load (KW)	8300	5300	5300	5300
Carnot Work based on 2.1K Operations:				
Primary Load (KW)	400	448	400	288
Liquefaction Load (KW)	102	27	27	27
Shield load (KW)	61	39	39	39
Total Load Carnot Work	**563**	**514**	**466**	**354**
Carnot Eff based on 2.1K Operations	**0.194**	**0.133**	**0.130**	**0.134**
Carnot Work based on 4.5K Operations:				
Primary Load (KW)	542	607	542	390
Liquefaction Load (KW)	102	27	27	27
Shield load (KW)	61	39	39	39
Total Load Carnot Work(KW)	**705**	**673**	**608**	**456**
Carnot Eff based on 4.5K Operations	**0.243**	**0.174**	**0.170**	**0.173**

Power Factor Implications

The Power Factor (PF) for all the cold compressor motors exhibits the following characteristic as shown in Figure 3 with respect to the speed.

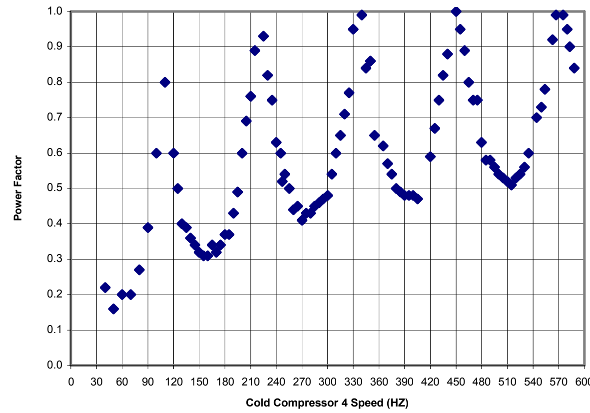

Figure 3: Power Factor vs. Cold Compressor Speed.

As a consequence the Cold Compressors' flow becomes unstable when any one of the cold compressor motors is approaching and operating near its minimum PF. The pump-down path (gear ratios) then has to be established such that the speed of the compressor lies below the motor current capacity limit (at the high suction pressures during pump-down) and no two compressor motors reach the minimum PF at the same time.

For the turn-down path the PF effect on speed is used to guide the speed adjustments so that no two compressors are reaching the low power factor for any speed adjustment simultaneously.

MAIN WARM COMPRESSORS TESTING

In March 2006, a series of tests were performed on the 1st and 2nd stage Howden [3] compressors at SNS, varying both the Built-In Volume Ratio (BVR) and the pressure ratio. The tests were performed for BVR's ranging from 2.2 to 3.8. 1st stage pressure ratios were varied from 2.57 to 3.80 and 2nd stage pressure ratios were varied from 3.64 to 7.46. Table 2 summaries the compressor data:

Table 2: SNS Compressors Data

	1st Stage	**2nd Stage**
Model #	MK6S/WLVI 321165/607	MK6S/WLVIH 321165/604
Motor Size	447 kW (600 Hp)	1864 kW (2500 Hp)
Rot. Diameter	321 mm	321 mm
L/D Ratio	1.65	1.65
BVR	2.2-5.0	2.2 – 5.0
Displacement @3550 RPM	94.61 m^3/s (3341 CFM)	94.61 m^3/s (3341 CFM)
Oil Charge	594 L (157 gal.)	397 L (105 gal.)

Figures 4 and 5 show the volumetric efficiencies for 1st and 2nd stage compressors.

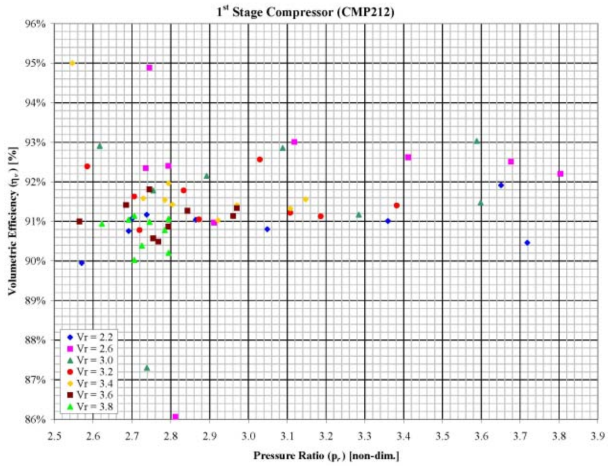

Figure 4: First Stage Volumetric Efficiency.

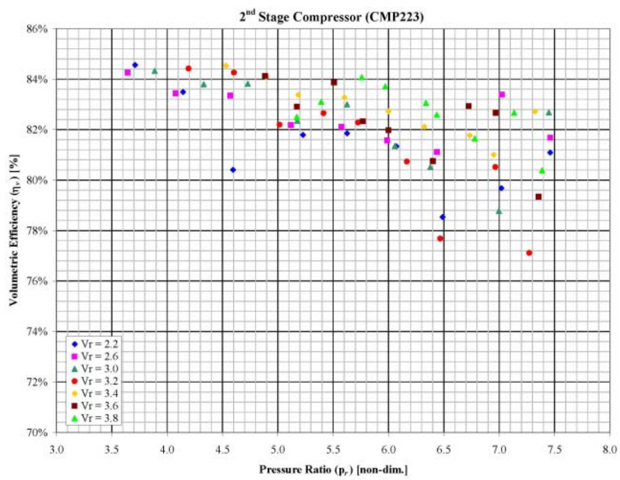

Figure 5: Second Stage Volumetric Efficiency.

Figure 6 and Figure 7 show the isothermal efficiencies for the 1st and 2nd stage compressors.

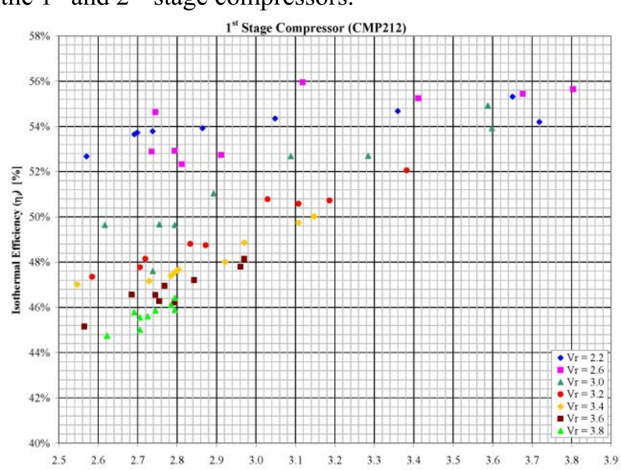

Figure 6: First Stage Isothermal Efficiency,

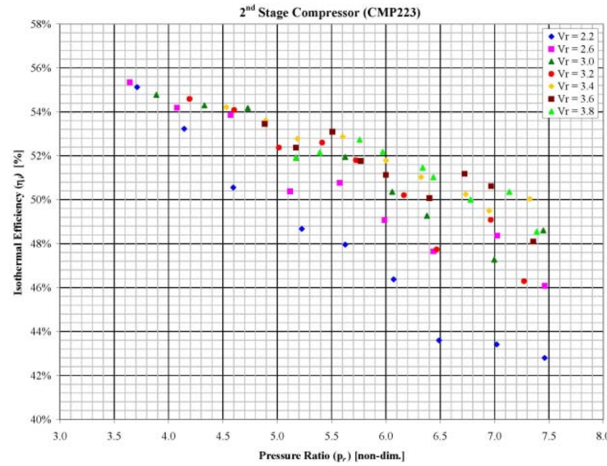

Figure 7: Second Stage Isothermal Efficiency.

The optimal BVR for a 1st stage compressor appears to be 2.2 to 2.6; for a 2nd stage compressor 3.0 to 3.4 (depending on the nominal operating pressure ratio) [4].

CONCLUSIONS

We have mapped the operation domain of the cryogenic system at 4.2K and 2.1K. We have investigated the warm compressor pressure ratio and internal volume ratio. We have investigated strengths and weaknesses of the actual components to minimize utilities and to understand the overall system capabilities.

REFERENCES

[1] F.Casagrande et al. “SNS Cryogenic Systems Commissioning” CEC 2005, Keystone, Colorado, USA

[2] P.Gurd et al “The Development of Automatic Sequences for the RF and Cryogenic Systems at the Spallation Neutron Source” ICALEPCS 2005, Geneva, Switzerland

[3] Howden Group Limited, Old Govan Road, Renfrew, PA4 8XJ, United Kingdom

[4] D.Arenius et al. “Screw Compressor Characteristics for Helium Refrigeration Systems” Cryogenics Operations 2006, SLAC, Stanford, CA