

EFFICIENCY ANALYSIS FOR THE CRYOGENIC SYSTEM AT NSRRC

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Abstract

Three superconducting magnets and one superconducting cavity for RF are cooled by two 450W liquid helium system at NSRRC. These two systems were made up of Claude cycle which is usually compared in their performance to that of the ideal Carnot cycle. This paper presents the efficiency analysis for the cryogenic system. Based on the analysis, the power transfer to the process change for the operation will be performed. In addition, it also shows the way to identify the problems when done the trouble shooting for part of erratic response of the plant. The Carnot efficiency also provides an important index for the performance, especially when we done the process control.

INTRODUCTION

To cooldown and maintain superconducting state of the SRF cavity and superconducting magnets, two helium refrigeration system had been installed since 2003 and 2007, respectively. The refrigeration capacity of these two systems was 450W and operated based on modified Claude cycle [1]. For the past few years operating periods, the cryogenic system has been experienced the predicable and unpredictable disturbances. A Part of these failures was caused the erratic dynamic response of the plant, for instance, the fluctuation of mass flow rate, temperature, and the reducing of liquefaction rate [2]. Even though the sequence programs were implemented to recovery these disturbances automatically, some of the problems still lead to a few days to back to normal condition. It is difficult to diagnosis the problems from the variation of the relevant parameters because they all followed the sequence programs. The most effective way to predict and seek the disturbance of the plant is to simulate the dynamic response of the variables. However it is almost impossible to anticipate the dynamic response of the variables such as, mass flow rate, temperature and pressure as a result of interaction in the plant process. Meakawa et al. [3] present the dynamic simulation of a large scale Helium refrigerator/liquefier, operated from 300 to 4.4K and discusses its validity of the model compared with the actual refrigerator. The performances and difficulties of process calculation under different conditions are also discussed. The dynamic simulator is a powerful tool to the process control and disturbance diagnosis. However, the solving procedures are complicate for the current application [4]. Based on the simply exergy analysis and efficiency calculation, the operating condition of the system could be summarized. Moreover, it is also help for checking the erratic response of the system.

This paper presents the exergy analysis and efficiency calculation method for the main cryogenic plant. Based

on these analyses, the “heat” generation and exergy change for the system were shown and discussed. Results also present the problems diagnosis by case study.

EXERGY ANALYSIS AND EFFECIENCY CALCULATION

The cold box has no input power and can only utilize the availability, the exergy, supplied to it by the compressor. Then, by throughing the exergy change inside the cold box from high temperature of gas helium to low temperature liquid helium. There are four parts of exergy change to the cryogenic plant, which were the compressor power generation, the refrigeration load, the liquefaction load, and the LN₂ precooling heat exchange. The formula to define the exergy change is written as [5]:

$$\frac{W}{\dot{m}} = T_0 \Delta s - \Delta h \quad (1)$$

Where, the $\frac{W}{\dot{m}}$ represents the work per unit mass (J/g),

the T_0 represents the compressor outlet temperature (K), the s represents the entropy (J/g-K), and the h represents the enthalpy (J/g). The exergy change of liquefaction depends on the exergy difference between compressor power production and the liquefaction. The refrigeration exergy change depends on the heat load of superconducting devices (three superconducting magnets, SMGs and one superconducting RF, SRF), the distribution valve box and multichannel line, the branch lines and its vacuum jacked connectors. The total heat load of these components for the present cryogenic system is about 310W which was indicated in table 1. The exergy change of LN₂ precooling depends on the mass flow rate for liquid nitrogen. The compressor power generation depends on the total mass flow rate of the helium gas. The efficiency was defined as the input power of a perfect Carnot cycle refrigerator over the actual compressor power that goes into the refrigerator. For the present study, it is defined as the sum of the refrigeration load and liquefaction load over the sum of the compressor work and exergy change of LN₂ pre-cooling.

Table 1: The heat load budget of the cryogenic system

	Heat load
SRF	90 Watt (the static and dynamic loss)
SMG	30 Watt (for three SMGs)
Valve box and multichannel line	30 Watt
Branch line to SMG	135 Watt
Branch line to SRF	25 Watt

RESULTS

The exergy change of Liquefaction rate and refrigeration power to the system efficiency

The efficiency calculation of the second main cryogenic plant commissioning was performed by using the exergy analysis. Figure 1 shows the variations of the Carnot efficiency to the refrigeration load and the corresponding liquefaction exergy changes. Results indicate that the Carnot efficiency was increased from 9.42% to 12.74% when the refrigeration load increase from 0 to 400kW, even though the liquefaction load decreased from 12.92kW to 1.83kW. This is because of the exergy increase of the cooling power is larger than the liquefaction exergy decreased. However, when the liquefaction load tends to zero which means the refrigeration capacity has already reached the limitation of the cryogenic plant. The efficiency was decreased from 12.74% to 12.46%, when the refrigeration load increase from 400W to 460W, respectively.

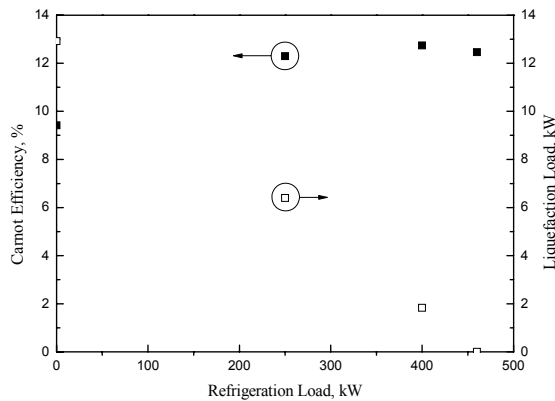


Figure 1: The variations of Carnot efficiency to the refrigeration load without LN₂ precooling

The exergy change of LN₂ precooling to the system efficiency

LN₂ pre-cooling is used to increase the system capacity by providing refrigeration for the first heat exchanger. The amount of the capacity is based on the setting temperature of the first heat exchanger. The lower of the temperature setting would have the larger refrigeration capacity. Figure 2 shows the variations of the Carnot efficiency of the system to the LN₂ precooling and the corresponding exergy change of the liquefaction load. It is seen that the efficiency increase from 12.25% to 12.81% when the exergy change of LN₂ increase from 3.8kW to 4.3kW. Results also indicated that the efficiency was increased rapidly in the range of 12.25% to 12.78%. This was perhaps due to the large difference of extra refrigeration power which was provided by the LN₂ precooling. The LN₂ provides the extra refrigeration power to the cryogenic which increase the Carnot efficiency of it. However, when the extra power is almost

equal to the returning refrigeration power (the power provided by the returning cold gas) the efficiency might reach the limitation.

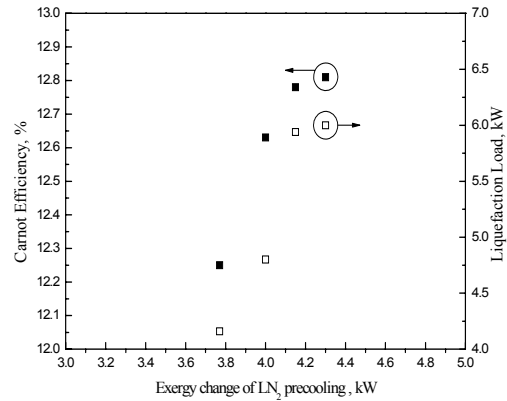


Figure 2: The variations of Carnot efficiency to the exergy change of LN₂ precooling

The partial cold gas lost to the Carnot efficiency

The installation of distribution valve box is used to switch the LHe supply and GHe return to the superconducting devices, which makes these two cryogenic systems, could be a back up to each other. However, it is found that the system might disturbance due to the leakage of the transfer line valves. Figure 3 shows the partial cold gas was leaked from first main cryogenic plant (MCP1) to second main cryogenic plant (MCP2), which reduced the cooling power of the MCP1 and decreased the Carnot efficiency and liquefaction load, respectively. It is seen that under normal condition, the Carnot efficiency for the (MCP1) is about 14.86% without LN₂ precooling and the liquefaction load is about 20kW. The first heat exchanger outlet temperature (T_{EX1}) is about 135K. When cold box lost the partial returning cold gas, the T_{EX1} was increased to 140K and the Carnot

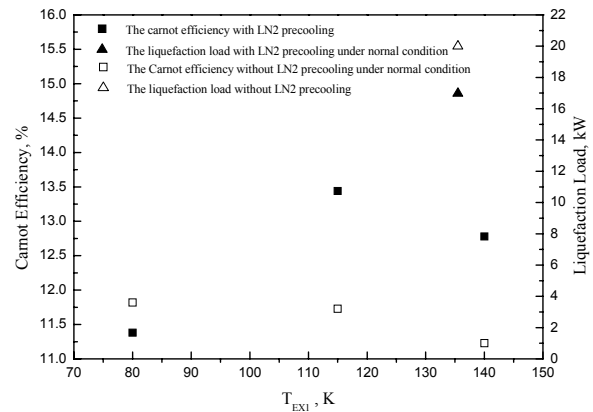


Figure 3: The variations of Carnot efficiency and liquefaction load to the first heat exchanger outlet temperature

efficiency and liquefaction load were decreased to 12.78% and 1kW, respectively. Even through the LN2 precooling power has increased, the efficiency and liquefaction load still down to 11.38% and 3.6kW, respectively at $T_{EX1}=80K$.

SUMMARY

This paper performed the simply exergy analysis and Carnot efficiency calculation. Results show that the variations of Carnot efficiency to the refrigeration power, the liquefaction load and the exergy change of LN2 precooling. By throughing case study, it shows that based on the efficiency analysis to summarize the power transfer which might be helped for the problems diagnosis, especially for the erratic disturbance for the system operation.

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