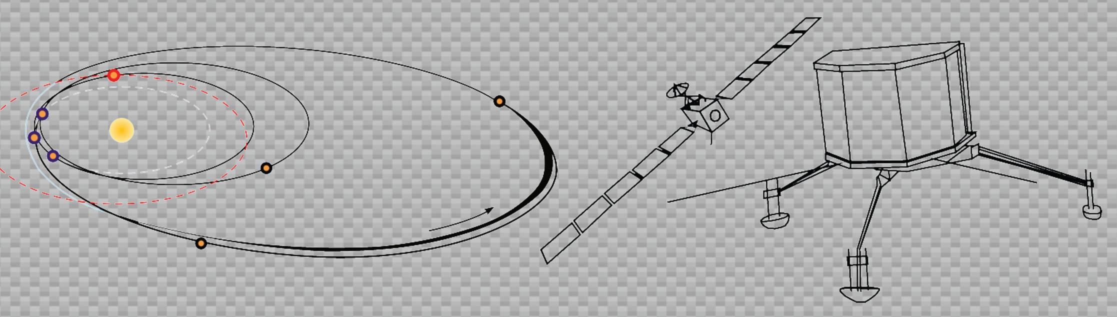
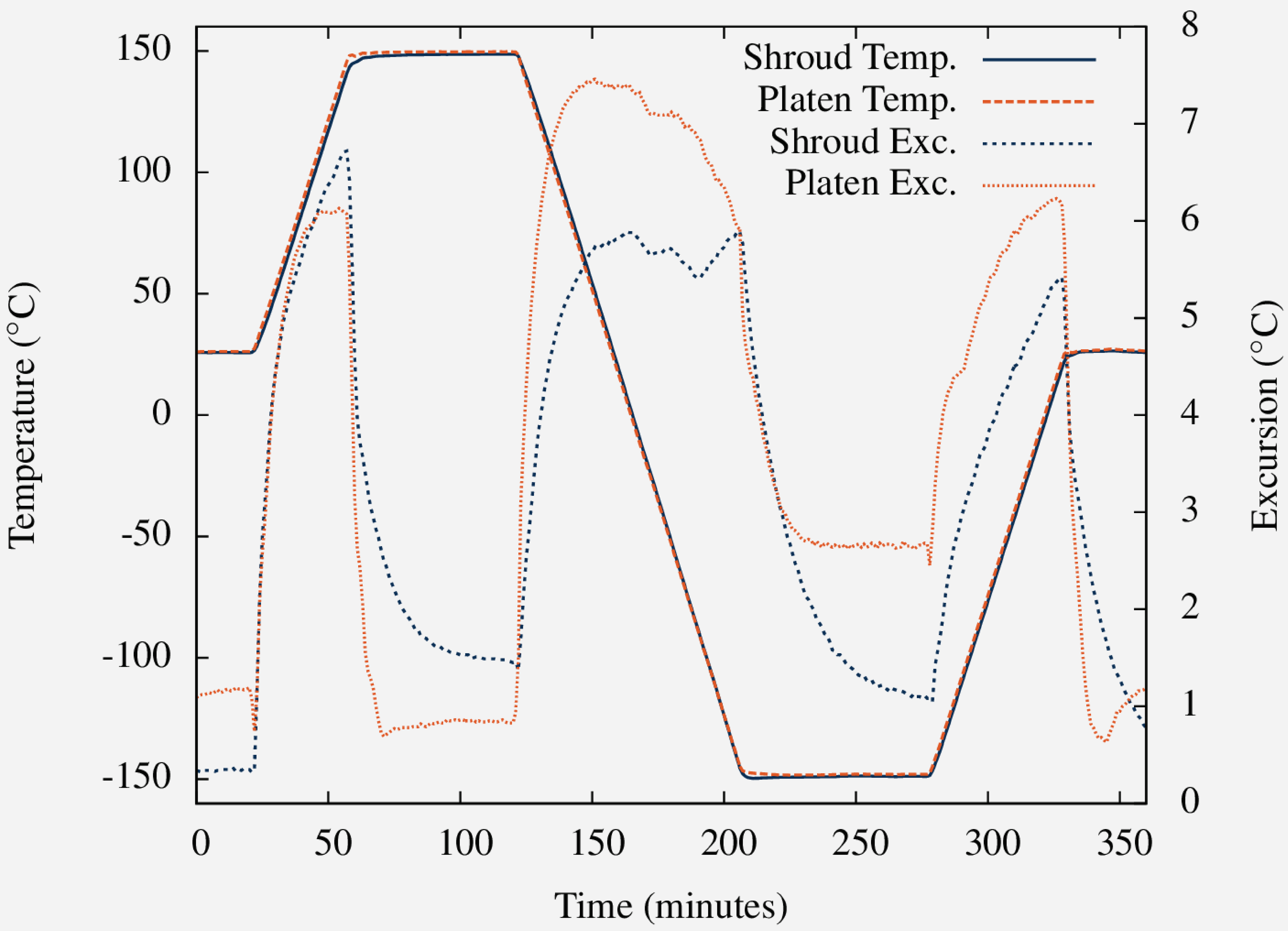


Improved Thermal Vacuum Chamber Temperature Performance via Gaseous Nitrogen Thermal Conditioning Units



Abstract

Many of today's thermal vacuum test programs require uniform and precise control over wide temperature ranges while minimizing operating budgets. This requirement has driven interest in energy-efficient gaseous nitrogen Thermal Conditioning Units (TCU) for temperature management of thermal shrouds and platens. Here we present recent improvements in TCU design for improved thermal performance. Compared to mechanical refrigeration systems, TCU's offer an increased temperature range (-180°C to 150°C) and avoid the possibility of chamber contamination via a shroud leak. Gaseous nitrogen TCUs also provide better temperature stability, set point control, and much reduced steady state liquid nitrogen consumption compared to flooded liquid nitrogen shroud systems. Furthermore, as that nitrogen closely adheres to the Ideal Gas Law, system modeling is relatively straightforward and system performance is quite predictable and stable. We will provide an overview of TCU characteristics, give examples of successful applications, and compare and contrast shroud performance. Methods for appropriately sizing Gaseous Nitrogen Thermal Conditioning Units will also be presented.

Overview

Thermal conditioning units are composed of a gaseous nitrogen circulator (or blower), a variable frequency drive (VFD) to control the blower speed, an inline heater, pressure measurement and control hardware, liquid and gaseous nitrogen supply valving, vent valving, mechanical or vacuum jacketed insulation, and a programmable logic controller (PLC) and Human-Machine Interface (HMI) for operation of the system.

At a most basic level, system properties can be easily modeled via the Ideal Gas Law,

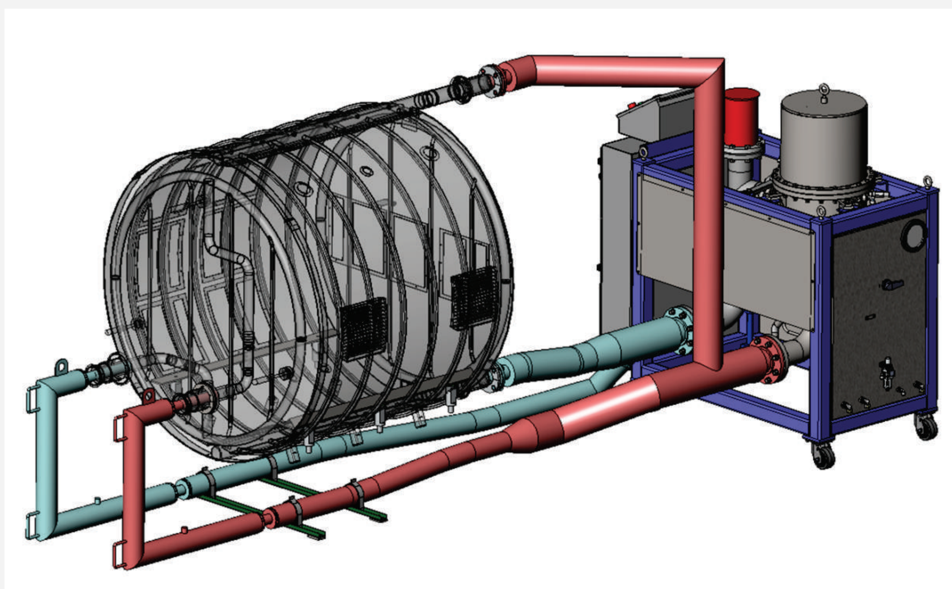
$$P = \rho R T$$

where P is the gas pressure in Pascals, ρ is the gas density in kg/m^3, R is the nitrogen gas constant, and T is the gas temperature in Kelvin. By operating the TCU at a constant gas density (usually 4-6 kg/m^3), the system exhibits a direct relationship between pressure and gas temperature. By controlling the heater power and injecting or venting gaseous or liquid nitrogen into the circulating circuit, the PLC is able to control the gas temperature and pressure in the system. This allows for easy control of the system over its entire temperature range, limited only by the liquefaction of the nitrogen heat transfer media and the upper temperature limit of seal materials and exterior paints.

At a given temperature, the heat transfer media must manage a heat load equal to the radiant heat transfer between the chamber and cryosurfaces, the active load of the test article, and the work of the blower, all mediated by the LN_2 injection and the inline gas heater.

During temperature transitions, the additional work required to move the mass of the cryosurfaces must be considered. At transition and at steady state one must also consider the difference in temperature between gas temperature and cryosurface wall temperature to avoid N_2 liquefaction at cold temperature (please see our conference paper for a further discussion on this topic).

Appropriately sizing TCUs for a thermal vacuum system requires accounting for a variety of system variables. Fundamentally, the TCU must provide a great enough gaseous N_2 mass flow and pressure head to manage the thermal loads of the system. Performance characteristics of four different sized while connected to an example thermal system (described at right) are presented in the table below.



Example Thermal System

We can use an example thermal vacuum test chamber to illustrate the performance of different sized TCUs. We assume an 1100-series aluminum cylindrical D-tube-on-sheet shroud, 1.3 m diameter by 1 m long by 3 mm thick, inside a 1.5 m diameter 1.2 m long cylindrical vacuum chamber. The shroud has six parallel D-tube runs, each connected to an input and output header and spaced by 175 mm. A 0.8 m by 1 m by 25 mm D-tube-on-sheet platen provides fixturing for a 25 kg test article. We will assume the test article uniformly radiates 1 kW. The bottom of the platen features seven parallel D-tube runs spaced by 150 mm to input and output headers. Front and rear end cap shrouds provide an encompassing thermal environment. The end caps are 1.3 m in diameter and 3mm in thickness, and feature eight parallel runs of D-tube spaced by 190 mm connected to input and output headers. The system is plumbed such that the nitrogen flow passes through the platen and the door in parallel, with the outlet of the platen split to drive the cylindrical shroud and rear panel.

Measured performance data of a single TCU400 ramping a platen and shroud both hot and cold at a set ±3 K/min ramp rate between -150°C and 150°C is plotted above. Maximum shroud and platen temperature excursions are plotted on the right axis.

	TCU100	TCU100BNB	TCU400	TCU1500
Flow Rate (m^3/hour)	170	170	680	2550
Head Pressure (kPa)	10	42	10	20
Steady State LN2 Consumption (L/min)	1	2	1.3	7
Transition LN2 Consumption (L/min)	5.5	5.5	10	48
Piping Diameter (mm)	50	25	100	150
D-Tube Diameter (mm)	19	12.5	31	41
Platen Gradient (K)	±0.75	±0.75	±0.25	±0.1
Shroud Gradient (K)	±8	±8	±2.5	±1.1
Achievable Ramp Rate (K/min)	±2	+2.25/-1.5	-4/+3.5	±18

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