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Capabilities of the Mars Electrostatics Chamber at Kennedy Space Center

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Abstract

The Mars Electrostatics Chamber (MEC) in the Electromagnetic Physics Testbed Laboratory at NASA Kennedy Space Center, a cylindrical vacuum chamber with a volume of 1.5 m^3, was designed to simulate limited Martian environmental conditions for electrostatics studies as well as for other areas of research. The MEC has been outfitted with an automated control system and a graphical user interface. The automation system consists of four subsystems: pressure control, temperature control, atmosphere control, and pneumatic control. The pressure and temperature control subsystems bring the chamber to 10 mbar and —90 C. The atmosphere control subsystem maintains a 100% carbon dioxide atmosphere at 10 mbar in the chamber. The pneumatic control system supplies compressed air to the pneumatic valves in the system. The MEC has a 1.43 m × 0.80 m experiment deck, a vacuum depressurization time of 20 min, controlled repressurization time of 10 minutes, and can be repressurized in an emergency in 10 min. The MEC can also be controlled manually to accommodate other environmental conditions. Experiments using the MEC are currently under way.

Introduction

The atmosphere on Mars is primarily 95% carbon dioxide with a few percent each of nitrogen and argon and contains only traces of water vapor. The atmospheric surface pressure, at about 6 to 9 mbar or 0.05 to 0.09 atm (5 to 7 torr) , does not provide enough pressure to prevent liquid water from boiling into vapor. This thin air, however, is dense enough to provide winds with speeds of up to 30 m/s. These winds create dust devils that can pick up dust particles from the surface. Fast winds can move airborne dust and form large dust storms that at times can engulf the entire planet.

The dry red dust and soil particles on the surface of Mars are composed mainly of iron and silicon oxides. Electrification of these particles can occur by contact or by friction between the particles themselves and when these particles interact with other surfaces [Kolecki 1991, Calle 1998]. The low atmospheric pressure near the surface of Mars makes electrification easier. It has been shown that a dust particle in a simulated Martian atmosphere may acquire as many as 10^4 elementary charges [Eden, 1973]. Ferguson *et al* interpreted the specularly reflected sunlight to a photovoltaic sensor on the Wheel Abrasion Experiment on the Mars Pathfinder rover to be due to dust electrostatically adhered to the rover wheel. Charge accumulation on surfaces may produce electrostatic discharges. Laboratory experiments have shown that filamentary and glow discharges can occur under simulated Martian environmental conditions [Eden, 1973]. Discharges of both kinds would be undesirable around sensitive electronic equipment. Moreover, electrostatically adhered dust can cause degradation of solar panels, heat radiators, and other such equipment in future Mars landing missions.

No experiment to determine directly the electrostatic characteristics of Martian soil and dust particles has been done and none has been planned for a landing mission until at least 2007. The Mars Compatibility

Assessment (MECA) electrometer, a multi-sensor instrument designed jointly at the Jet Propulsion Laboratory and at Kennedy Space Center for the cancelled lander in the Mars 2001 mission, was supposed to measure the electrostatic charge generated by the Martian soil when rubbed against five different insulating materials [Buehler 2000]. This instrument (or an improved version) is now expected to fly on the 2007 Mars landing mission.

The Mars Electrostatics Chamber (MEC) was designed at the Electromagnetic Physics Laboratory at Kennedy Space Center to test and calibrate the MECA electrometer and to characterize the electrostatic interaction between Martian simulant dust particles and several materials that might be used in future missions to the planet. The MEC was designed to simulate Martian atmospheric pressures and temperatures as well as atmospheric composition for different latitudes and different seasons.

Physical and Operating Characteristics

The MEC is 2 meters in length, 1.3 meters in diameter, and has a volume of 1.5 m^3 (Fig. 1). The chamber has a 1.43 m $\times$ 0.80 m experiment deck, a vacuum depressurization time of 20 min, controlled repressurization time of 10 minutes, and can be repressurized in an emergency in 10 minutes. Access ports are provided for component and peripheral device feed-through. In addition, ports are used for existing pressure measurement, thermocouples, and gas feed-throughs. Access ports are also provided for monitoring payloads. The inside of the chamber has been fitted with a cooling shroud. The chamber has been outfitted with an automated control system and a graphical user interface. The MEC operating characteristics are listed in Table 1.

Figure 1. The Mars Electrostatics Chamber (MEC).

Table 1. Mars Electrostatics Chamber Operating Characteristics

Operating Characteristics	Minimum	Typical	Maximum
Operating Pressure	0.3 mbar	9 mbar	1013 mbar
Operating Temperature	150 K	170 K	473 K
Pneumatic Line Pressure		760 kPa	860 kPa
Chamber Pressure			130 kPa
Cooling Line Pressure			1000 kPa
Bakeout Temperature		420 K	473 K
Bakeout Pressure		0.7 mbar	

Automation Systems

The automation system installed on the MEC consists of three major systems: pressure control, atmospheric control, and temperature control. All functions of the chamber are directly or indirectly controlled and monitored by a central programmable logic controller (PLC).

The *pressure control system* is used to lower the pressure of the chamber to that of the Martian atmosphere using a primary and a backup secondary pump. A throttle valve is used to control the rate of pressurization. A pressure controller is used to operate the throttle valve.

The *atmospheric control system* is utilized to monitor and maintain the gasses contained within the chamber. A residual gas analyzer (RGA) has been partially integrated with the system to provide information on atmospheric gas composition. The RGA is operated manually but readings are sent to the LabVIEW graphical user interface. The software that operates the RGA has been installed on the computer. When the chamber pressure reaches 13 mbars, the RGA displays the atmospheric contents of the chamber provided that the RGA software has been initialized. Communication between the RGA and the computer is achieved via RS-232 serial communication. The RGA is the only device that is not directly or indirectly controlled by the PLC that has been installed. A mass flow controller maintains the desired concentration of atmospheric gas within the chamber.

The *temperature control system* replicates temperatures within actual minimum and maximum values as would be experienced on Mars. A liquid/gaseous nitrogen supply is used to obtain this temperature range, as well as various heating techniques. Fundamental to the stabilization of temperature within the chamber was the optimal control of extremely cold nitrogen. After testing and characterization, significant cooling implementation design changes, and controller instrumentation modifications, this cryogenic supply was successfully manipulated by the PLC system with appropriate programming.

Gaseous nitrogen (GN_2) is drawn from two dewars. Two solenoid valves are used to select the dewar to be used at a given time, providing for continuous flow. Warm GN_2 from the building supply is mixed with the cold GN_2 from the dewars to prevent CO_2 condensation in the chamber. A turbine flow meter measures the flow of GN_2 while an analog cryo control valve controls the flow. Figure 2 shows the control system. Cooling flows through a single line into the chamber and is channeled into eight zones before being vented to the exterior of the building.

Sixteen tape heaters located in four zones around the chamber as well as warm GN_2 are used to heat the chamber. Forty-eight thermocouples are used for temperature measurement in the chamber. Four of these are flexible and are used to measure the atmospheric temperature in the chamber. Other thermocouples provide temperature information on various part of the experiment deck.

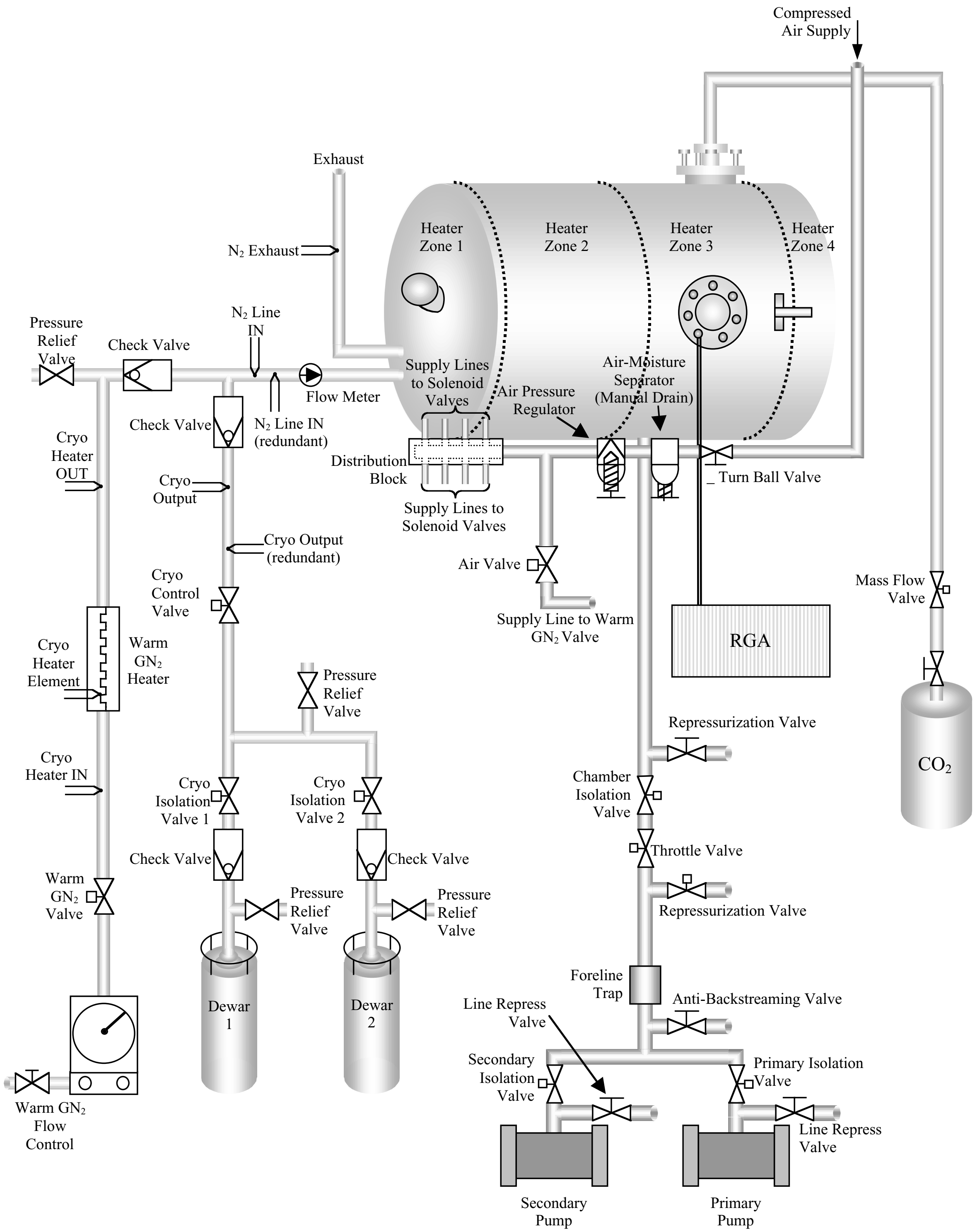

Figure 2. Control System configuration

A long duration cooling test for a set point of 150 K is shown in figure 3. The Read Chamber IN line is maintained constant at the setpoint temperature of 150 K in spite of the large fluctuations of the cryo input from the dwars (Cryo Output) and the cryo line. The chamber atmospheric temperature maintains a steady approach to the steady-state final temperature.

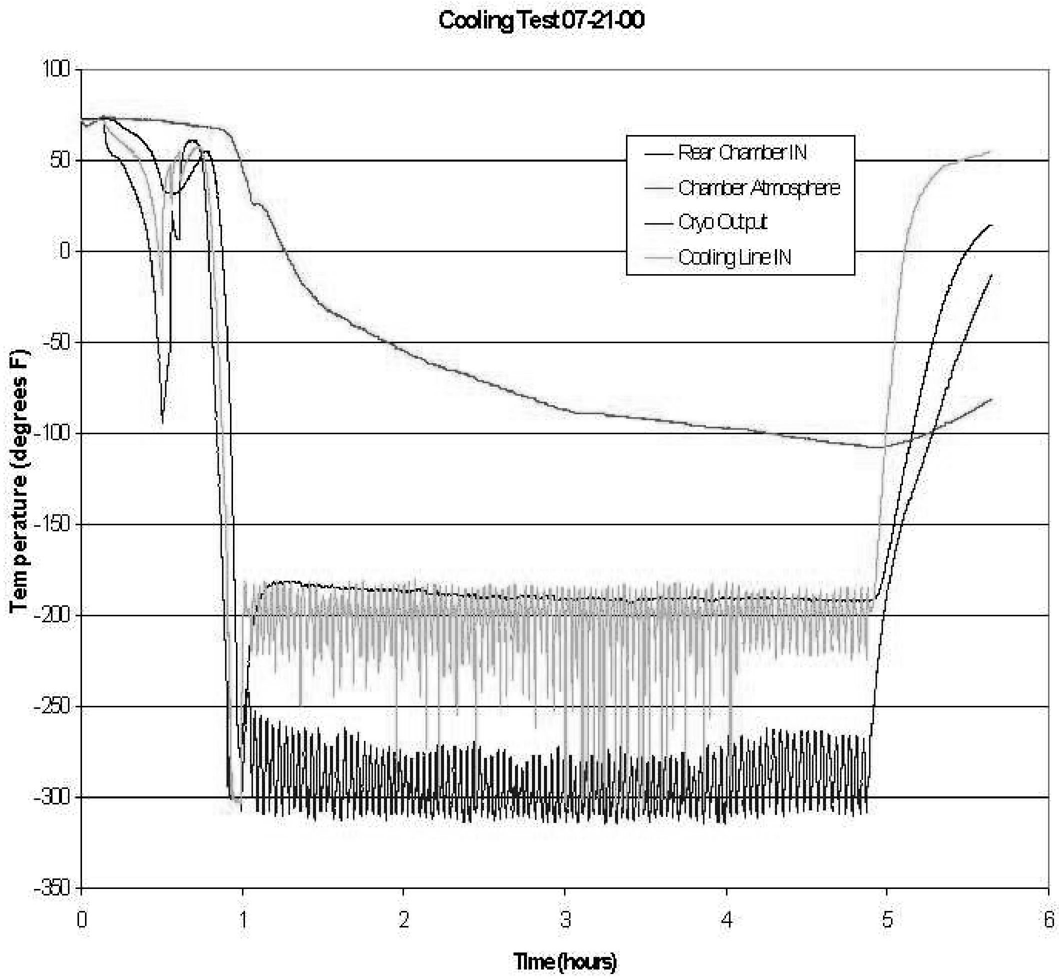

Figure 3. Long duration cooling test for a set point temperature of 150 K.

Hardware and Software Configuration

The PLC is the heart of the whole system. The PLC accepts inputs from the manual control panel, capacitance manometers, flow meters, pressure controllers, and thermocouples. The PLC provides outputs to the manual control panel indicators, vacuum systems, heater system, automated sequence hardware, atmospheric gas valve, alarm, pressure system outputs, warm GN_2 valve, pressure system displays, and cryo system outputs. Numerous outputs are sent to the LabVIEWvirtual panel as well.

The MEC has been outfitted with a graphical user interface (GUI). This interface has soft controls and indicators that emulate the physical control panel with the addition of elaborate graphical management capabilities. The program oversees system functions such as vacuum, temperature, data recording, and system set point control, monitoring, trending, charting, and graphing functions. The GUI notifies with the PLC when it is ready to accept or provide information relative to the control process. The PLC was designed not to initiate communication since it is programmed to control the complete vacuum and cooling process independent of virtual supervision or intervention. The GUI is used to monitor all aspects of the chamber operation that of interest to the user and to provide a convenient method of inputting user-defined parameters.

Operational Overview

The chamber can be operated in a complete automated mode. The automatic mode is activated either form the computer LabVIEW master control panel or from the manual pushbutton panel by pressing the Auto Sequence Initiate button. In this mode, the automatic sequence begins with the activation of the primary pump and the opening of the primary isolation valve (Fig. 2). The pressure controller opens the valve and the chamber is evacuated to 1.5 mbar. The mass flow valve is then opened to begin backfilling the chamber with atmospheric gas (CO_2, or a premix matching the actual composition of the Martian atmosphere). When the pressure reaches 9 mbar the cooling sequence can start and the analog cryo control valve is opened. The warm GN_2 valve is also opened to supplement the flow of cryo and to ensure vaporization of any liquid nitrogen. A flow meter monitors the flow rate of the mixture.

The pressure, temperature, and atmospheric content are monitored and maintained automatically by the system throughout the duration of the test. There is opportunity for user involvement, but it is not necessary. The chamber can run autonomously for any length of time that the LN_2 dewar and atmospheric gas supplies are provided.

At the end of the experiment, the program runs the automatic shutdown sequence to return the chamber to ambient temperature and pressure. At this point, the atmospheric gas flow is halted. The cryo isolation valves and the cryo control valve are closed while the warm gas continues to flow through the shroud. The warm GN_2 heater is turned on to heat the warm GN_2 gas. The tape heaters are activated in all four zones to assist the warm GN_2 heater in warming the chamber. Once the chamber reaches room temperature, the primary isolation valve is closed and the primary pump is deactivated. The automated repressurization valve is then opened and the throttle valve is used to control the rate of repressurization of the chamber.

If an experiment needs to be stopped and the chamber brought up to room conditions, the Auto Sequence Abort or the Emergency Abort buttons can be used. The Auto Sequence Abort pushbotton disables Auto Sequence Initiate. When activated, the chamber valve, throttle valve, and primary isolation valves are closed. The primary vacuum pump is disabled and the heater zones are enabled to bring the chamber back to ambient temperature. The Emergency Abort pushbutton disables all chamber systems and brings the chamber to ambient pressure as quickly as possible. To activate this function, the user pushes the button for ten seconds. This function is available at any time during any mode of operation.

The chamber can also be operated manually without the use of the computer user interface from the Manual Control Panel. This Manual Control Panel was developed to add more flexibility to the chamber and as an alternative to the graphical user interface controls. This panel allows experimenters to select individual functions and perform manual tests while still maintaining the safety associated with an automated system. All functions of the Manual Control Panel are redundantly provided on the virtual user interface.

Conclusions

To fill the need for the increased research activity around NASA s exploration of Mars, the Electromagnetic Physics Testbed at Kennedy Space Center activated the Center s first operational Mars environmental simulation chamber, the Mars Electrostatics Chamber. Several important environmental characteristics of Mars have been replicated in this chamber, including temperature, pressure, and atmospheric composition. Integration of existing and newly acquired hardware with a centralized controller was performed to bring about successful near-autonomous operation. The automated operation brings the chamber to a simulation of the Martian environment with default pressure and temperature values. Since the surface pressure on Mars varies slightly and the temperature has large variations due to season and latitude, these values can be easily changed from the graphical user interface LabVIEW graphical user interface program. Manual operation capabilities have also been provided.

A User Manual with detailed instructions on the safe operation of the chamber has been developed and is available in the laboratory. A comprehensive Technical Manual has also been developed to help the technical personnel in the Electromagnetic Physics Laboratory troubleshoot the chamber [Buchanan 2000].

The MEC was developed to conduct experiments in the characterization of the electrostatic properties of Martian soil and dust simulants, to test and calibrate the MECA electrometer, to characterize the electrostatic response of different space materials to charged and uncharged simulant dust and soil particles, and to help our laboratory in the development of new science payloads and instruments for the study of the environmental problems near future spaceports on Mars. Experiments on the MEC are currently under way.

There are now plans to install a lighting system that simulates the solar radiation spectrum on the surface of Mars. Future development programs for the chamber include the creation of several automated simulation scenarios to account for the variation in surface temperature and pressure at different latitudes and seasons and the development of an automated diurnal cycle that would include the appropriate changes in temperature and radiation.

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