Engineering Notes

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Pressure Sensing and Controller Development

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Nomenclature

P_1 = initial propellant vapor pressure at engine firing signal
P_2 = lower limit of the control band during pressurization and expulsion
P_3 = upper limit of the control band during pressurization and expulsion
P_4 = vent valve open pressure
P_5 = vent valve closed pressure
ΔP_2 = minimum NPSP = $P_2 - P_V$
ΔP_3 = run pressure dead band + ΔP_2
P_V = instantaneous vapor pressure
P_T = instantaneous total pressure

Introduction

CRYOGENIC space propulsion systems involving multiburn operations, long coast times, and zero venting will require a pressure sensing and control system to minimize pressurant gas consumption, and to maximize the time that the propellant feed system can be maintained in space until the tank vent pressure is reached. Two prototype controller systems were developed for these conditions, one for a hydrogen (H_2) and one for a fluorine (F_2) feed system. This Note briefly describes the development and the controller operation. The system sensing conditions within a space vehicle propellant tank and provides appropriate electrical signals for opening and closing both vent and pressurization valves while satisfying preset pressure limits. A special venting capability is also included to provide relief in the event of overpressure resulting from unexpected conditions, such as abnormally high heat flux, and to allow propellant tank conditioning prior to prepressurization.

Discussion

At the outset of the program, a limited feed-system analysis was conducted to assess two basic control system approaches, as applied to a Mars Orbiter Orbit Injection Stage: 1) fixed ΔP_T control, where the minimum total tank pressure during engine operation is determined by having the control system add the preset NPSP to the measured total tank pressure at the time of the firing command signal; and 2) true NPSP control where the minimum total tank pressure during engine operation is determined by having the control system add the preset NPSP to the actual propellant-vapor pressure. These two control approaches are illustrated in Fig. 1. A hydrogen-tank pressure history for a selected multiburn case is shown here. The history includes the effects of heated He vapor

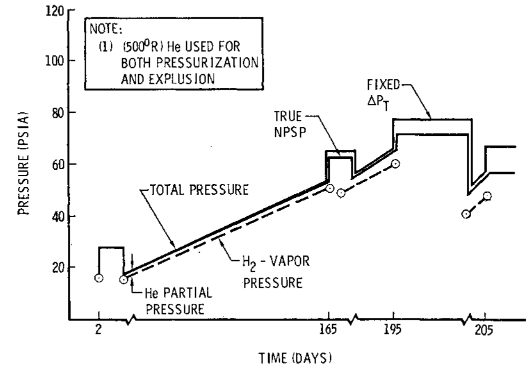

Fig. 1 LH_2—tank pressure history

for prepressurization and expulsion pressurization. The solid line represents total pressure and shows the effects of propellant heating, the prepressurization required for the NPSP, pressurization levels during the burn, and the decay levels after firing. In all the cases studied, performance gains resulted by using the true NPSP control approach. Due to the apparent advantage, this approach was incorporated into the design.

Four types of total pressure transducers: 1) thin film strain-gage, 2) capacitance/digital, 3) variable impedance, and 4) variable reluctance, were evaluated for use with the controller. The variable impedance pressure transducer was selected because of its superior long term performance. Tests performed in liquid hydrogen further proved the instrument capable of making accurate measurements at −423°F.

The measurement of P_V and the solutions of P_T = (NPSP) + P_V represent the true NPSP. A platinum resistance temperature transducer and its associated signal conditioning unit were selected for this measurement. The vapor pressure is sensed in terms of temperature for both LH_2 and LF_2 and the system internally, within their signal conditioning, linearizes the inherent vapor pressure/temperature resistance anomalies.

The electronic logic portion of the system was designed to be compatible with the selected sensors. The system provides electrical (28 v d.c.) signals to two vent valves (one explosive and one solenoid) and two pressurant supply solenoid valves. The commands to open and close these valves are based on the instantaneous inputs P_T and P_V along with certain preset pressure limits. A pressure profile is illustrated in Fig. 2 to show the controller standby and firing operations. ΔP_2, ΔP_3,

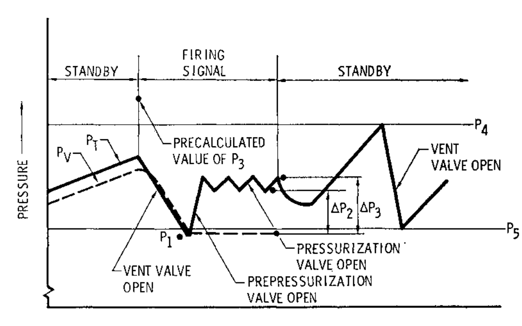

Fig. 2 Controller operations

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P_4 and P_5 are electronically preset references analogous to pressures and pressure differentials. ΔP_2 is the minimum NPSP. The run pressure dead band is $\Delta P_3 - \Delta P_2$ and P_4 and P_5 are the upper and lower limits of the vent pressures, respectively. During standby, P_T is monitored and the vent valves are opened as required by the tank pressure. When the firing signal is input to the controller, the standby cycle is terminated and the firing cycle starts. Initially a precalculation is performed to determine whether the prepressurization would result in $P_3 > P_4$. For this condition, the system is vented to P_5 before prepressurization takes place. This operation allows for conditioning the propellant by lowering its P_V. When prepressurization is complete, an appropriate "prepress complete" signal is output until the firing signal terminates. The system is pressurized during the remainer of the firing cycle. When the firing signal terminates, the controller switches to the standby operation.

The packaging of the electronic logic portion of the system was predicted on the use of discrete components and integrated circuits mounted on standard logic cards. Transistor-transistor logic (TTL) integrated circuits are used in the digital portion of the controller. The card cage containing 19 cards was wire-wrapped with No. 30 gauge wire. The signal conditioners associated with the two P_V and P_T sensors are mounted in the controller enclosure and 20 ft cables separate these sensors from the signal conditioners. An A/D converter is used to accept the 0–5 v analog signal from either pressure transducer signal conditioner and outputs an 8-bit binary word. Solid state valve driver circuits convert 3.5 v logic level signals to 28 vd.c. power signals which are used for valve actuation.

Testing

The testing consisted of simulating the total tank pressure and the propellant vapor pressure while allowing the controller to function automatically according to the present pressure values. In these functional tests, the controllers were placed in a 10^{-6} torr vacuum while the sensors were chilled down and maintained at $-423°F$ using liquid hydrogen and at $-320°F$ using liquid nitrogen as required by the LH_2 and LF_2 units, respectively. The output voltages from the sensors, valve drivers, prepressurization complete signal, 8-bit digital signals, and the power regulators were measured. Calibrations were performed before and after the functional testing of each unit. Test data are presented in Table 1 where initial conditions are tabulated along with the ideal and actual (measured) values of P_2, P_3, P_4, and P_5.

Measured data for P_3 and P_4 were slightly higher than ideal because of pressure overshoots resulting from the setting of a relatively slow A/D converter sampling rate (1.0 sec) as compared to a rather rapid test pressurization rate (2 psi/sec).

Table 1 Test data

Test no.	Initial conditions (psig)		Test results (psig)			
	P_1 Vapor press	P_T Total press	P_2-NPSP Ideal	P_2-NPSP Actual	P_3 Ideal	P_3 Actual
1[a]	20.8	20.6	29.7	30.1	32.7	35.4
2[a]	20.8	40.5	29.7	30.0	32.7	35.0
3[a]	43.8	61.5	36.1	36.5	39.1	42.2
3[a]	[c]27.2					
		P_T	P_4		P_5	
4[b]		59.5	50.5	49.0	37.1	37.0

[a] Firing operation.
[b] Standby operation.
[c] This change in P_v represents the venting and propellant conditioning.

The range of sampling rates at which the controller can function is 0.020 to 1.2 sec. A faster rate would most certainly improve the controller performance for these cases. A true measure of performance was made by the separate calibrations of the sensors and controller. Here the maximum static error for the controllers, independent of the transducer inputs, was 0.6% of full-scale (200 psig) and the sensors output maximum static errors were: 0.6% for the total pressure and 1.2% and 2.5% for the H_2 and F_2 vapor pressure measurements, respectively.

The test results showed that the controllers functioned in the manner for which they were designed. The basic prototype design can be directly applied to the flight model requiring only minor mechanical and electrical changes.

Reference

[1] Wachtler, W. J. and Tobolski, J., "Pressure Sensing Control Development for Pressurization and Venting Systems," Final Rept. CR-73748 Aug. 1970, NASA.

Performance of a Staged Combustion Rocket Motor

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Introduction

OVER the years numerous schemes have been proposed for effectively decoupling the fuel preparation phenomena and oxidizer preparation phenomena from the combustion processes occurring in bipropellant rocket motors. Hopefully such decoupling would result in increased combustion stability, improved combustion efficiency, wider latitude in propellant selection, and improved ignition characteristics. One of the more promising of the proposed schemes is the staged combustion mode of rocket motor operation. In the staged combustion rocket motor under consideration all of the oxidizer (N_2O_4) was reacted with a small portion of the fuel (a 50–50 blend of UDMH and N_2H_4) to produce hot oxidizer rich gases in the primary chamber. The major portion of the fuel was injected into the hot oxidizer gases as they entered the secondary chamber or combustion chamber. To increase the decoupling effectiveness of the staged combustion cycle, the oxidizer gases were injected into the secondary combustion chamber at slightly supersonic velocity. It was believed that any high-frequency combustion oscillations generated in the combustion chamber could not propagate into the primary chamber and affect the oxidizer preparation phenomena. The severity of the starting transients or ignition

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