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PROPULSION SUBSYSTEM COMPONENT DEVELOPMENT PROGRAM FOR THE MECB RSS SATELLITE

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José N. Hinckel, Vladimir J. Trava-Airoldi,
Evaldo J. Corat and Cláudio Bressan

INPE – Instituto Nacional de Pesquisas Espaciais
12225 – São José dos Campos – SP – Brazil

Abstract

The development program for satellite propulsion system at INPE is presented. All components for the reaction control system, including hydrazine tank, fill and drain valve, latch valve, hydrazine filter, control valve and monopropellant hydrazine catalytic thruster are being built and tested. The system is designed to satisfy the propulsion requirements of three-axes stabilized remote sensing satellite designed by INPE, to be launched in 1995. The thruster test facility and measurement techniques are described.

Introduction

The MECB RSS satellite has a design life of two years, at a sun-synchronous orbit. Two satellites will be built, to be launched two years apart. The mass of the spacecraft after separation from the launch vehicle is approximately 170 kg. Design and testing of the propulsion system components is being done at INPE. The contractor for fabrication is COPESP (Coordination for Special Projects). This paper describes the design of the components and presents the results obtained from the prototypes already tested. The qualification requirements for the system are also described.

Propulsive Requirements

The satellite will be launched by the all solid propellant launch vehicle under development at the IAE – Institute for Aeronautics and Space. The injection orbit is elliptic 350 by 550 km high. After separation, the propulsion system will provide the impulse for the maneuvers described in table 1. The orbit raising maneuver will be performed by using 4 or 8 thrusters at the same time. The maneuver will be performed over several orbits.

Subsystem Description

The propulsion subsystem is illustrated in Figure 1. Two half assemblies are interconnected on the liquid side. Each assembly is composed of a pressurant fill and drain valve, hydrazine tank, filter, latch valve and 6 thruster assemblies. The latch valves isolate the lines in case of fail open of a control valve in that line. A single fill and drain valve is used to load the hydrazine in both tanks. The pressurant gas is nitrogen. The blowdown ratio is 4:1, from an initial value of 22 bar to 5.5 bar.

The thrusters are mounted in two pods, one of them containing 8 thrusters and the other, 4.

The Test Facility

The thruster test facility is located in the propulsion laboratory at INPE in São José dos Campos.

The vacuum chamber is 2 m long and has a diameter of 1.8 m. The vacuum system is composed of Roots and Rotary pumps with pumping speed of 4 m^3/s for a chamber pressure below 10 mbar. A high capacity diffusion pump is also available. Ultimate chamber pressure, for the system operating with mechanical pumps only, is below 10^{-3} mbar. With the diffusion pump, the ultimate chamber pressure is below 10^{-7} mbar.

The hydrazine feed line is equipped with pressure and flow measurement devices and temperature conditioning system. Steady state flow measurements are

Maneuver	Δv (m/s)	Prop. mass (kg)
1. Acquisition Phase		
- Rate reduction mode		0.27
- Sun Acquisition		0.11
- Nominal attitude acq.		0.06
- Orbit Transfer	139	12.5
- Inclination correction	66	5.6
- Attitude control		0.5
2. Operational Phase		
- Orbit keeping	23	1.29
- Wheels dessaturation		1.65

Table 1: Propellant budget

performed with a Max Machinery Model 213 piston flow meter. A Viscojet and a differential pressure transducer can also be used. The accuracy of the steady state flow measurement is better than 1%.

In pulsed mode operation the amount of hydrazine for each individual pulse is measured by integrating the pressure drop across the Viscojet. The amount of hydrazine for each pulse is measured with an accuracy better than 5%.

The temperature of the propellant hydrazine can be controlled, from 10 to 70°C.

Data acquisition and analysis are performed by an HP-9000 computer, and a multiprogrammer with a 32 dual-channel, a scanner and a 500 kHz ADC.

The control valve is commanded by the computer-multiprogrammer system.

All raw data from the tests are dumped to the computer memory via a DMA and stored in a hard disk. After each run, the raw data are analysed and operating parameters of the thruster are computed. The processed data are displayed on the computer monitor, hard-copyied in a printer or plotter or stored in magnetic tapes.

After processing, the raw data are stored in magnetic tape.

The catalytic chamber pressure is measured with Kistler piezoresistive or piezoelectric transducers.

The pressure drop across the Viscojet is measured with two Kistler piezoresistive transducers, or with a wet-wet Druck differential pressure transducer.

Special care is taken to avoid gas bubbles between the upstream pressure pick-up port and the injector head. When this condition is satisfied, the width of the pulse of pressure difference is approximately the same as the time that the control valve remains open. In this case, the amount of hydrazine injected in each pulse can be precisely calculated.

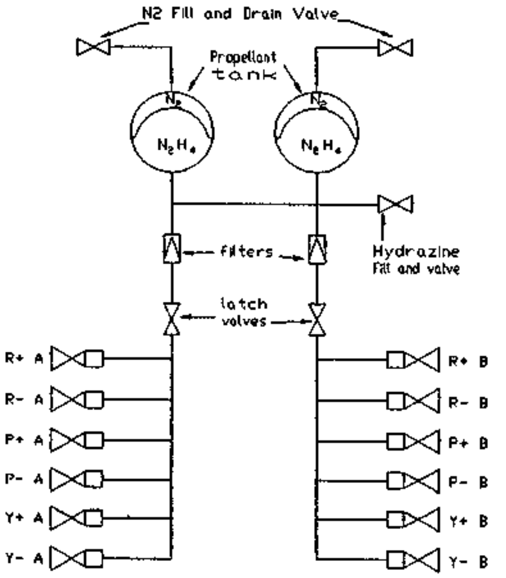

Figure 1: Propulsion subsystem schematic

The steady state correlation for pressure drop and flow rate is used to integrate the flow rate during each pulse.

A specially designed thrust balance was constructed and calibrated. The thruster is mounted in the horizontal position to table supported by two flexures. The thruster force is measured with a load cell attached to the thruster support table. Static calibration of the system is performed with the thruster connected to the feed tube and all cabling and thermocouple connected.

The Hydrazine Tank

The hydrazine tank has a total volume of 16.2 liters. The tank has a 131 mm long cylindrical section and two hemispherical caps with a diameter of 260 mm.

The tank is fabricated in titanium alloy Ti6Al4V. Two identical caps with a cylindrical section are superplastically formed and machined to a thickness of 0.7 mm for the spherical cap and 0.8 mm for the cylindrical section. The caps are welded together by laser welding. A connection tube is welded to each cap.

An EPDM membrane separates the hydrazine from the pressurant gas.

The design requirements for the tank are listed below:

Operating pressure:	22 bar
Proof pressure:	30 bar
Rupture pressure:	40 bar
Dry mass:	< 2 kg

One tank with the dimensions described above has been built and tested. The tank was cycled 20 times to the proof pressure and then pressurized till rupture whick occured at 51 bar.

The Latch Valve

The latch valve, Figure 2, has two coaxial coils, separated by the ferrite magnet. The magnetic circuit

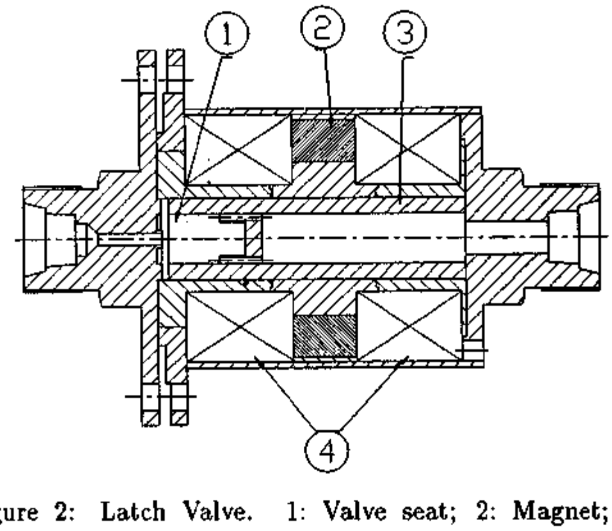

Figure 2: Latch Valve. 1: Valve seat; 2: Magnet; 3: Popet; 4: Coils.

has two stable positions, with the valve open and closed. The transition from one state to the other occurs with the application of a short current pulse to one of the coils.

The axially moving popet has a travel path of 0.3 mm. A Hall cell is used to indicate the status of the valve. The valve seat is fabricated in EPDM.

Two models have been built and tested. The main results obtained were the following:

- In the closed position and under pressure the Helium leak rate was less than 10^{-6}torr·l/s.

- The magnetic locking force, in the closed or open position, resists acceleration up to 50 g along the axis of the popet.

The Fill and Drain Valve

The fill and drain valve, Figure 3, is also machined in titanium alloy. The seat and the bushings are fabricated in teflon. The valve has three series seals.

The Thruster Assembly

The thruster assembly is illustrated in Figure 4. The control valve has a single teflon/metal seat. A flat spring keeps the valve closed. The valve exit orifice is 1.4 mm. The magnetic circuit is adjusted during assembly in order to obtain repetitive opening and closing times. A detailed description of the valve is presented in [2].

The ıjector head, catalytic chamber and nozzle are machined in Inconel 600 and welded together by electron-beam or laser. The injector orifice has a diameter of 0.2 mm and is drilled with a high speed drill.

The nozzle throat is carefully polished to within a tolerance of 0.01 mm. The nozzle divergent is conical with 15° half-angle and area ratio of 50:1.

The Inconel capillary tube has inner diameter of 0.5 mm and is welded to the valve flange and injector head by laser.

The chamber diameter of 6.7 mm provides an adequate bed pressure drop and chamber loading. The chamber pressure is measured through a pick-up port at the beginning of the convergent section of the nozzle.

Before the catalyst is loaded into the chamber, the orifice flow coefficient is measured and calibrated to the design value. A fine adjustment is made by squeezing the capillary tube.

Shell 405 ABSG 20 to 30 mesh catalyst is used. During the loading process, the thruster is attached to a shaker and vibrated at 250 Hz and 1.5 g.

Three series connected cartridge heaters are welded to the catalyst chamber. A thin walled thermal shield surrounds the chamber and nozzle to minimize radiation losses during pre-heating process and to protect the nearby surfaces form the high thermal load during the thruster operation.

A chromel-alumel thermocouple is also welded to the outside wall of the chamber.

Thruster assembly test performance

Three thruster assemblies were built and tested. All three models were subjected to a complete life-cycle teste.

In the first two models the thruster performance was derived from the measurements of the feed pressure, chamber pressure and propellant flow. Good agreement between design value and measured value was observed for chamber pressure and flow rate.

In the third model thrust measurements were also performed. In this case it was possible to compare the results obtained from direct measurements and those calculated from the chamber pressure measurements.

The thruster was initially subjected to a performance mapping test. In this test the thruster was subjected to diferent propellant supply pressures and pulse width. Three propellant supply pressure levels were tested: 5.5, 10 and 22 bar. The pulse width were 50, 100, 200 and 500 ms. For all tests, the pulse frequency was 1 Hz, so that the duty-cycle ranged from 5% to 50%. A total of 12 firings were performed, one for each pressure level and pulse width. All firings started with the thruster pre-heated to a temperature bete-

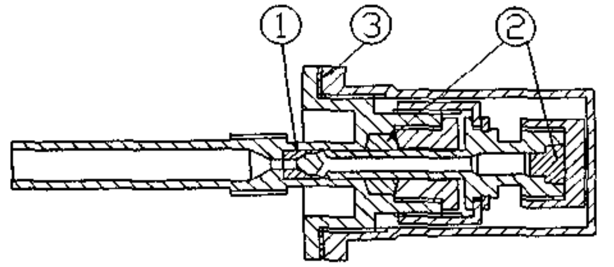

Figure 3: Fill & Drain Valve. 1: Primary seal; 2: Secondary seals; 3: Third seal.

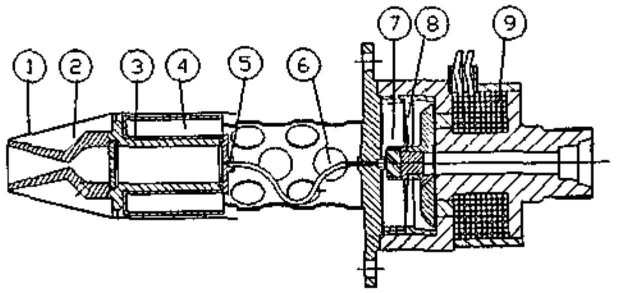

Figure 4: Thruster assembly. 1: Radiation shield; 2: Nozzle; 3: Catalytic chamber; 4: Heater; 5: Injector head; 6: Capilary tube; 7: Valve seat; 8: Spring; 9: Coil.

ween 95°C and 150°C.

For each pressure level, a continuous firing with a duration of 100 seconds was also performed.

After the performance mapping the thruster was subjeted to a life–cycle test. This test consisted of 20 thruster firings with 1000 pulses. Each sequence of pulses started from a temperature of 150°C. The tank pressure and pulse width were changed from one firing to the other between the same values as used during the performance mapping.

Two 20 minutes continuous firings were also performed. Five cold starts, from temperature of 23°C were performed.

Finally, a performance mapping similar to the initial one was performed.

Cold pulses, starting from temperature of 23°C were also performed. In these pulses, pressure spikes in the catalyst chamber, with amplitudes of up to 200% the average chamber pressure value were observed. These spikes were caused by the delay in the hydrazine decomposition. Delays of up to 200 ms were observed, which is long enough to fill 20% of the chamber free volume with liquid hydrazine, and hence large spike after decomposition is initiated.

Qualification requirements for the thruster are listed below:

Pre–heated starts (from 95°C):	1000
Cold starts (from 35°C):	50
Total number of pulses:	30.000
Accumulated impulse:	30.000 Ns

Figures 5 and 6 show the pressure trace for a continuous firing and for pulsed mode operation, respectively.

The steady state performance of the thruster is shown in Figure 7 against the design curve.

Peak–to–peak chamber pressure oscillations was approximately 12 % the value of averaged chamber pressure for a tank pressure of 22 bar. As the tank pressure decreases, the oscillations become stronger with a peak–to–peak value of 20 % at a feed pressure of 5.5 bar.

The frequency of the chamber pressure oscillations was approximately 70 Hz.

In the initial pulses of the pulse trains, the amplitude of the pressure oscillations was considerably smaller than during the rest of the pulses when the thruster chamber temperature had attained its steady state value.

In the first and second models, pressure spikes of up to 100% the average chamber pressure were observed during *some* pulse trains, or continuous firings. The spikes usually occured between 10 and 20 seconds after the start of the pulse train or the continuous shot. Since the wall temperature transient time is of the order of 20 seconds the spikes were assumed to be related to this transient.

A detailed calculation of the temperature distribution in the injection region was performed. The calculated temperature at the interface between the wall and the hydrazine was above 600°C.

Thermal decomposition of the hydrazine in the capillary tube, before the injection orifice would cause high feed pressure and therefore a spike in the catalytic chamber.

To verify this conclusion, a cold nitrogen jet was directed against the injector head during the firings. The spikes disappeared altogether in most firings.

In the third model the injector head was modified in order to reduce the temperature of the hydrazine–wall interface. With these changes the chamber pressure spikes were completely eliminated. It was also observed that the amplitude of the chamber pressure oscillations were reduced, specially for the low feed pressures.

The pulsed mode performance is shown in Figures 8, 9 and 10. The data shown in these figures were obtained from the tests of the third model constructed.

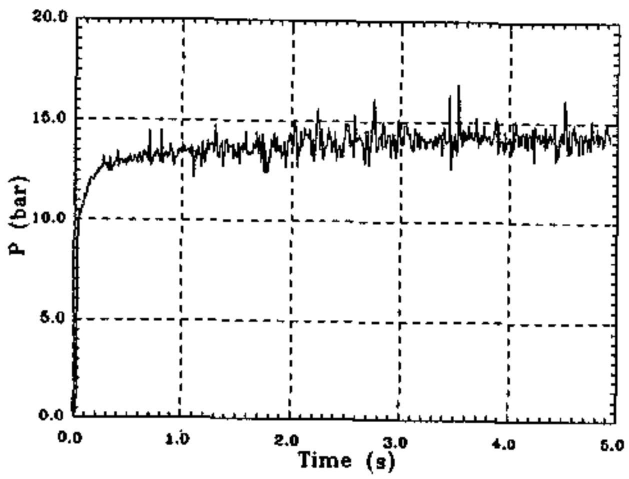

Figure 5: Pressure trace for a continuous firing. P_i: 22 bar.

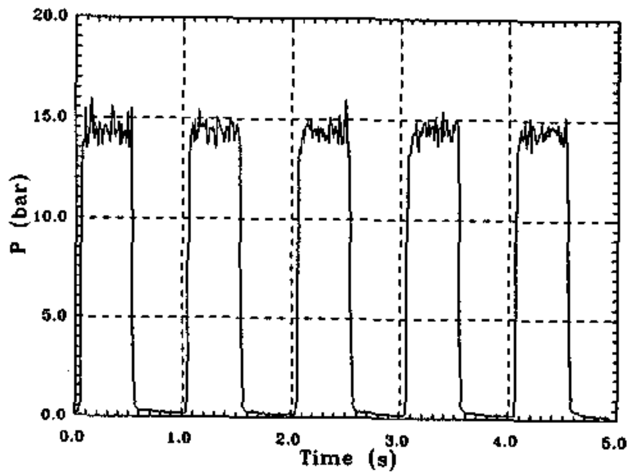

Figure 6: Pressure trace for pulsed mode operation. P_i: 10 bar

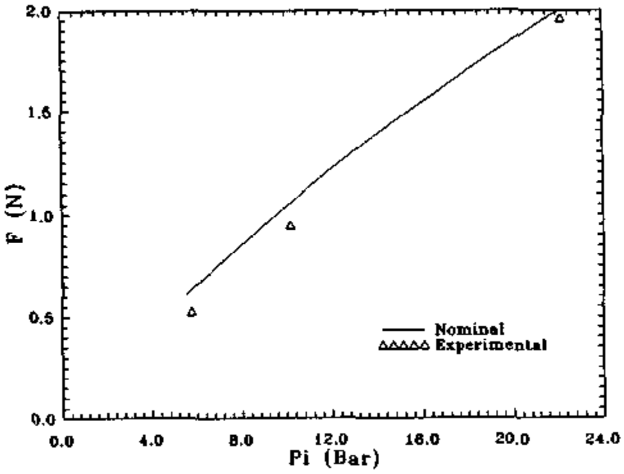

Figure 7: Steady state thruster performance

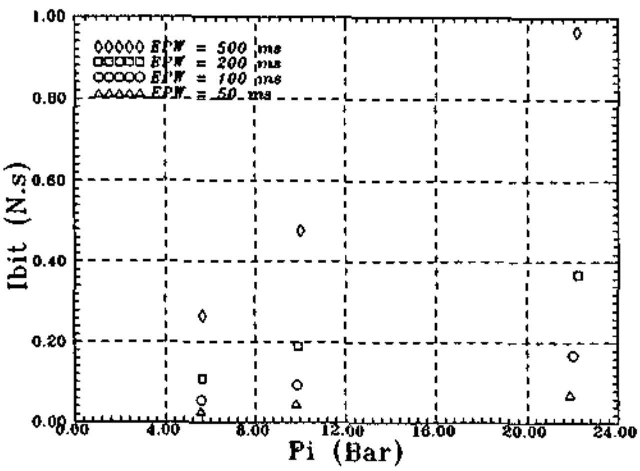

Figure 8: I_{bit} vs supply pressure and pulse width

The I_{bit} are those obtained from the thrust measurements.

In Figure 8 the I_{bit} capability of the thruster over a wide range of duty-cycles and feed pressures is shown.

In Figure 9 the I_{bit} for a 100 pulse train is shown. During the the first five pulses the I_{bit} increases markedly. After the 10^{th} pulse, it remains approximately constant with pulse to pulse variations less than 3%.

In Figure 10 the I_{sp} corresponding to the I_{ibit} from Figure 9 are shown. As shown in this Figure, the specific impulse increases markedly during the ten initial pulses, and continues to increase to lower rate through the 50 subsequent pulses. During the last 40 pulses it remains approximately constant. The final value is different for different feed pressures.

The increase in the I_{is} is closely associated with the temperature of the thruster chamber and catalyst. The temperature of the thruster chamber for the same pulse trains is shown in Figure 11.

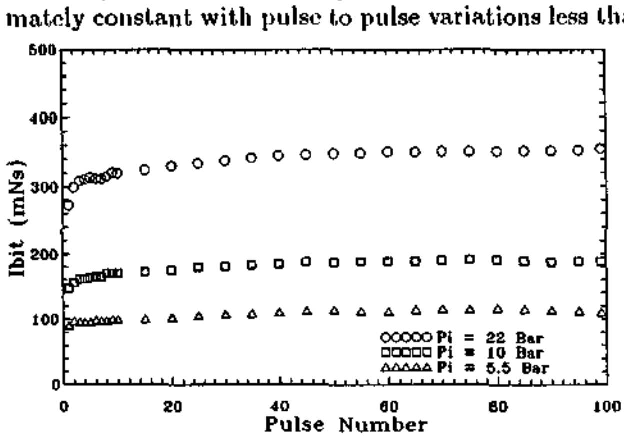

Figure 9: I_{bit} vs pulse number. EPW = 200 ms

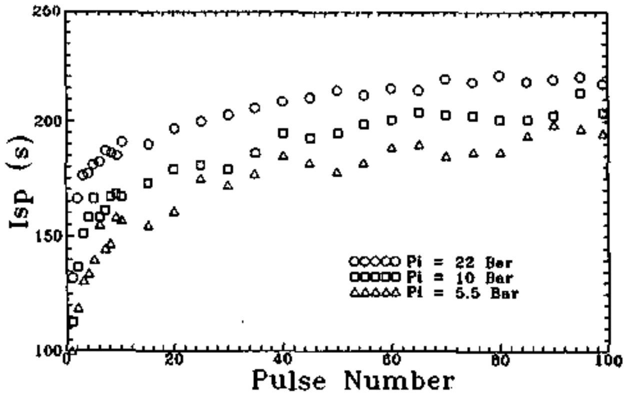

Figure 10: I_{sp} vs pulse number. EPW = 200 ms

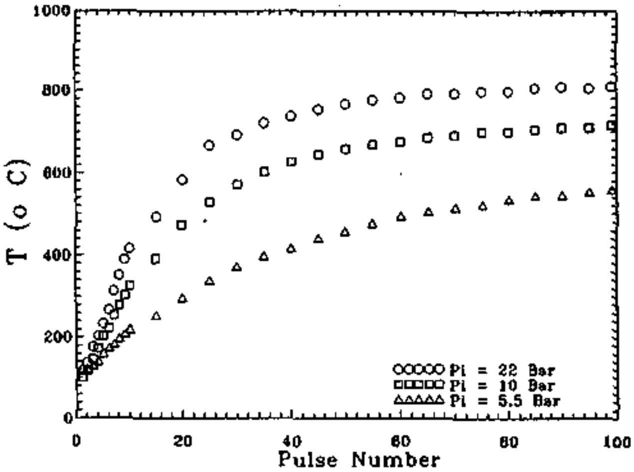

Figure 11: Thrust chamber temperature vs pulse number. EPW = 200 ms

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[1] Rocket Research Corporation. Development of Design and Scaling Criteria for Monopropellant Hydrazine Reactors employing Shell 405 Spontaneous Catalyst. Seattle, Wa. 1965. (NASA CR 82456).

[2] Corat, E. J. and Trava-Airoldi, V. J., An efficient, high-repetition-rate fast-pulsed valve. Review of Scientific Instruments. 61(3), March 1990.

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AUTOR

José Nivaldo Hinckel, Evaldo José Corat, Vladimir J.T. Airoldi

TRADUTOR

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Catalytic Thruster, Hydrazine Tank, Control Valve, Latch Valve

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