DEVELOPMENT AND TESTING OF ELECTRONIC PRESSURE REGULATOR (EPR) ASSEMBLY

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ABSTRACT

Most large modern satellites utilise bipropellant propulsion system with the fuel and oxidizer being expelled under constant pressure from the storage tank to the motor for apogee boost and either bipropellant and/or electrical propulsion systems for attitude and/or orbit control.

The actually preferred method of controlling pressure in such systems is a mechanical pressure regulator. For a few electrical propulsion systems already an electronic pressure regulator is introduced.

The electrical propulsion system will become more popular in the future and for the next years mainly combined chemical, electrical systems will be used.

The aim of the Astrium GmbH , Space Infrastrucure, propulsion group is to develop and qualify a system based on electronic pressure regulation with common definition for use on chemical and electrical propulsion.

An electronic pressure regulator assembly allows the optimum pressure adjustment in order to achieve :

- optimum ISP for selected mission phases (electrical and chemical propulsion)
- minimise propellant residuals by individual adaptation of pressures (mixture ratio for chemical propulsion)
- lead to lower complexity of propulsion systems
- minimise mass and cost.

The EPR presently under development and testing at Astrium GmbH, Space Infrastructure, is designed to fulfil the requirements for electrical and chemical propulsion system.

1. Short Technical Description

A typical EPR equipment blockdiagram for chemical propulsion system is presented in figure 1:

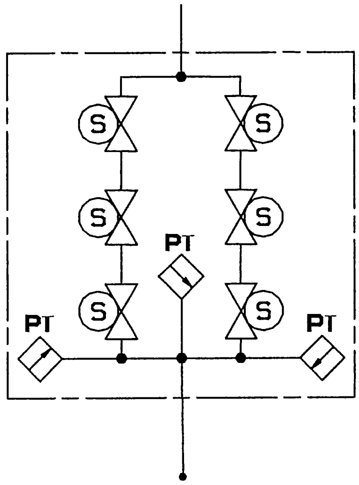

Figure 1 : EPR Equipment Blockdiagram

Thus the EPR consists of:

- Two branches with three solenoid valves each,
- Three low pressure transducers
- A ¼" inlet and outlet tube interface
- One common assembly bracket

As shown in figure 1, two branches of three solenoid valves in series are used for pressure isolation and regulation in conjunction with the low pressure transducers.
Function and operation of the EPR is as follows. Any two solenoid valves of one branch of valves are opened and then kept open at a low voltage in the order

Proc. 3rd International Conference on Spacecraft Propulsion, Cannes, 10-13 October 2000, ESA SP-465, December 2000

of a few Volts for minimised power consumption. The remaining (third) valve is pulsed in a way to regulate the pressure in the propellant tanks and to keep it within the predefined pressure range. The low pressure transducers measure the regulated pressure and thus give the information to the control electronics for operation of the regulating valve. The EPR can achieve the required regulated pressure within a pressure range at the EPR inlet of approx. 300 bar down to 2.5 bar. The three valves used in the EPR are designed for a MEOP of 500 bar.

Redundancy exists with respect to the low pressure transducers (reading two out of three) and above all for the pressure regulation by means of the two solenoid valve branches. Each valve per branch can be used for pressure isolation and for pressure regulation.

The two valve branches providing serial and parallel redundancy are assembled into one housing. Each valve is operated from a single coil and is equipped with a hard seat using tungsten carbide as seat material to achieve a good leak tightness and a high cycle life capability.

2. Typical Propulsion Missions

2.1. Chemical propulsion

Typical chemical propulsion missions are providing the necessary Δ-V for apogee manoeuvre in regulated mode and the Δ-V for station keeping and de-orbiting in blow-down mode.

The selection of the operational pressures has to be performed in a very early stage of the programs for the adjustment of the mechanical pressure regulator, based on analytical results.

The EPR assembly provides following advantages when compared with the mechanical one:

- Pressure range for apogee manoeuvre can be selected based on the main engine data in orbit
- Readjustment of pressure range based on in orbit firing results can be performed
- By the implementation of two EPR assemblies the optimum mixture ratio can be selected
- The optimum set points for the propellant tanks at the start of the blow-down mode can be selected in orbit incl. maximum use of pressurisation gas on board

2.2. Electrical propulsion

For the electrical propulsion system the optimum combination between the requested Δ-V´s ,the available power and the necessary thrust can be selected by the adjustment of the inlet pressure.

The variation of outlet pressure is possible within the requested fields of electrical thrusters (typical range between 5 to 1 bar)

3. Implementation in propulsion design

3.1. Bipropellant systems

For the implementation into bipropellant systems mainly two possibilities exist:

a) Replacement of mechanical regulator by EPR

Including this possibility would provide all the advantages mentioned in 2.1 except the selection of mixture ratio.

General Blockdiagram is provided in figure 3.1-1.

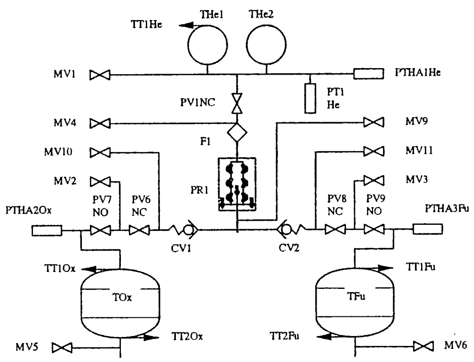

Figure 3.1-1: Replacement only

b) Implementation of two EPR assemblies

By the implementation of this possibility the complete propulsion system can be simplified by deletion of several armatures like pyro valves and check valves.

The EPR assembly is fully compatible with the propellants and the relevant propellant vapours.

During launch also three inhibits from the high pressure part to the low pressure part are provided.

By implementation of this solution all the advatages mentioned in 2.1 are provided.

General Blockdiagram is provided in figure 3.1-2.

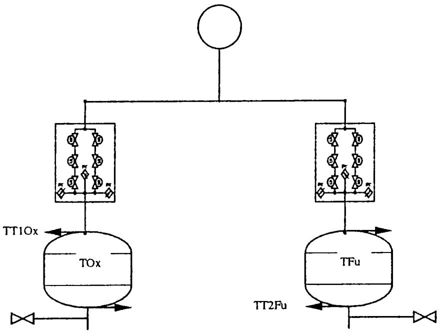

Figure 3.1-2 : Optimum Solution

3.2. Electrical Propulsion Systems

For the implementation into electrical propulsion systems the EPR assembly includes also the plenum, needed for the requested accuracy of regulation and medium supply.

The EPR assembly provides the full redundancy normally requested and the relevant inhibits for safety reasons.

The definition of the EPR assembly for electrical propulsion system application is shown in figure 3.2-1 and the possible implementation into complete system in figure 3.2-2.

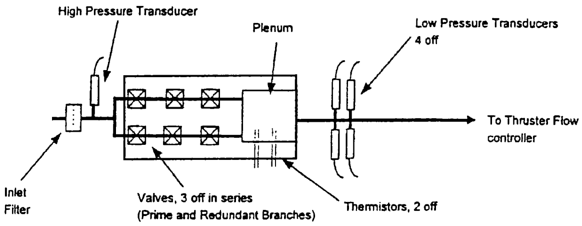

Figure 3.2-1 : EPR Assembly for electrical propulsion System

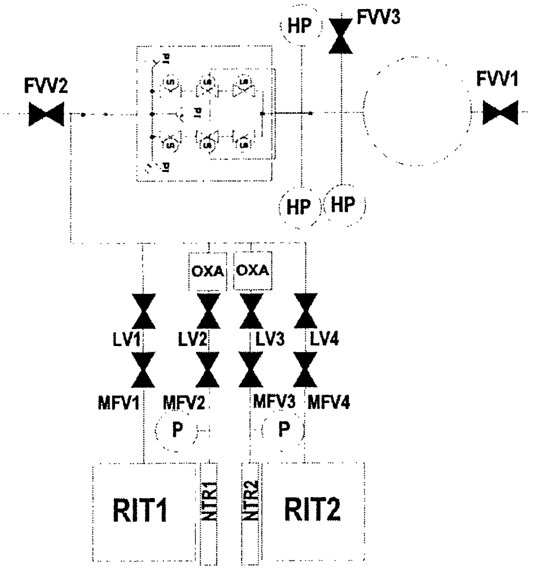

Figure 3.2-2 : EPR Assembly implemented in electrical propulsion system

4. Summary of requirements for EPR development

	Chemical	Electric Prop.
• Pressures : Inlet :	400 to 30 bar	270 to 5 bar
Outlet :	15 to 22 bar	0.1 to 5 bar
• Mass-flow :	0 to 0.6 g/s GHe	0.04 to 20 mg/s Xenon
• Flow Stability :	± 0.5 %	± 0.5 %
• Reg. Pr. Stability :	< ± 0.1 bar	< ± 0.1 bar
• Op. Media:	Helium	Xenon

- Testmedia : N2, Argon, IPA, deion. Water
- Leakage internal : ≤ 5 x 10-4 scc/sec GHe
- Leakage external : ≤ 1 x 10-6 scc/sec GHe
- Nom. Supply Voltage : 24 ± 5 VDC or 50 ± 5 VDC
- Power consumption : 40 W max. (cycling)
- Mass : ≤ 2.5 kg
- Environmental Loads : standard known figures

- Temperature requ. : - 15°C to + 40 °C
- Mounting : 4 x M4 screws
- Interface : Tubing : 1/4" titanium
  Electrical : TBD with system

5. Detailed EPR Design

The EPR Assembly consists of two branches of three solenoid valves in series mounted on one common assembly bracket and covered by the main housing used as plenum.

The general overview is shown in figure 5-1.

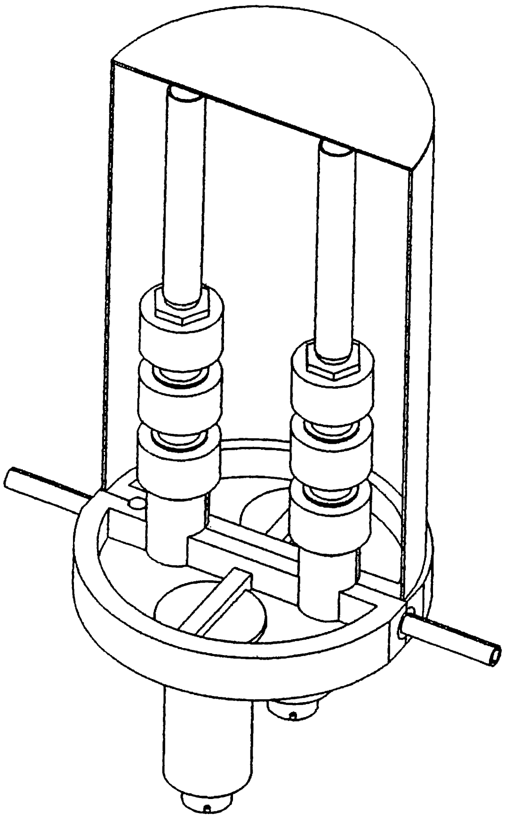

Figure 5-1 : General Overview

This overview presents the inlet tube on the left side and the outlet tube on the right side.

On the common assembly bracket the two sets of solenoid valves are mounted, by using screwed connection. This screwed connection provides redundant sealing by metal and O-ring .

A single branch of valves is shown in figure 5-2.

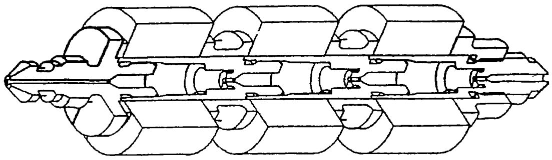

Figure 5-2: Single branch of valves

This branch consists out of three solenoid valves which are pretested as single valves and then welded together to the valve branch.

The inlet of valve set is mounted on the common assembly bracket by screwed connection as mentioned before. The outlet of the valve set is open to the plenum, the two tubings shown in figure 5-1 at the top of the valve are used to support the valve set for the environmental loads.

On the bottom of the assembly bracket the low pressure transducers are mounted. This unit is providing the low pressure value within the plenum and provide this information to the control electronics for the activation of the regulating valve.

The plenum volume is also used for the cooling of the active valve set, since during activation there will be always gas flow through the plenum.

At the inlet branch of the EPR assembly it is possible to mount also the high pressure transducer and a helium inlet filter to avoid additional equipment on the propulsion system and to minimise tests and mass.

A similar design will be used for the electric propulsion system, only the volume of the plenum will be adapted to the relevant requirements of the system.

The complete EPR assembly can be mounted by four M4 screws on the relevant structure part of the system.

The titanium tube ends are designed for 1/4 " connection to the propulsion tubing. For this connection welding as well as cryo-fit connection can be used.

The complete EPR Assembly is compatible with the standard fluids and gases as mentioned in para 4.

The parts of the assembly and the valves which might be in contact with the propellant for bipropellant systems are also tested for their compatibility.

6. Development Results

Presently a lot of tests have been performed by Astrium GmbH for the definition of the baseline design for the EPR Assembly.

All tests have been performed in the frame to define a common solution for the application on chemical and electrical propulsion systems. The testing has been performed by using commercial electronic parts for the definition of the electronic circuit. Also the mechanical parts like valves and pressure transducers are aero-space parts, whereby the definition of the requirements for space application was respected. The supplier of the valves for the development testing will also supply the valves for the final design. For the pressure transducer several suppliers can provide the units as requested.

For the electronic control circuit a standard measuring trigger instrument including potentiometers for adaptation as shown in figure 6-1 was used.

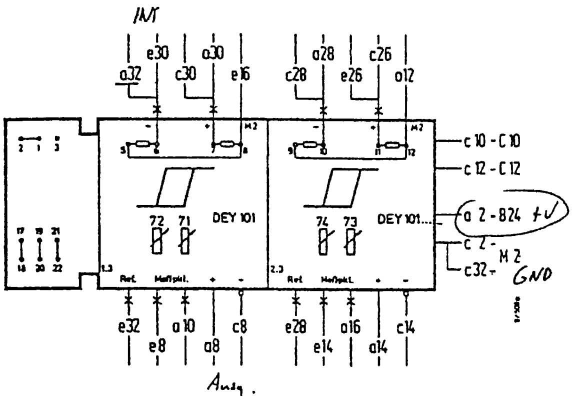

Figure 6-1 : Electronic circuit

The aim of the testing was to define the impact of the different configurations and electronic circuits application to the regulation behaviour of the EPR Assembly.

One major step during this testing was the definition of the plenum volume impact on the regulation accuracy.

The outcome was that already with a small volume of the plenum in the area of 1 litre the regulation accuracy will be within the defined stability of ± 0.1 bar.

By increasing of the volume up to about 4 litres a regulation stability of < ± 0.05 bar can be achieved.

Taking into account the available volume in the propellant tanks for chemical propulsion, acting also as plenum, a very small plenum for application on chemical systems can be implemented.

Typical regulation plots for plenum between 1 and 4 litres are shown in figure 6-2.

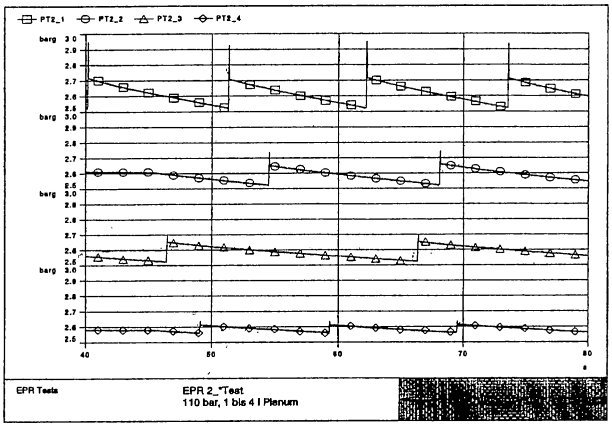

Figure 6-2: Regulation plots for plenum between 1 litre (top) and 4 litres (bottom)

For the application on chemical propulsion tests have been performed simulating main engine activation and the complete nominal mission.

A typical plot is shown in figure 6-3. The definition for this test has been: Nominal flow of 0.4 g/s GHe , EPR inlet pressure starting at 300 bar down to 30 bar.

The plot in the middle provides the outlet pressure stability, which is well within the definition of ± 0.1 bar. The plot at the bottom shows the flow rate, where no variation can be detected.

The chosen ullage volume (plenum plus propellant tank) for this testing was about 36 litres.

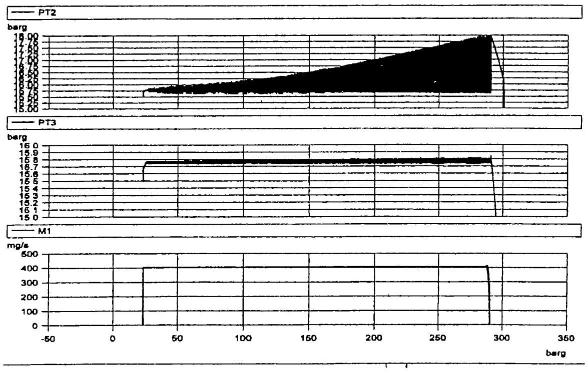

Figure 6-3 : Regulation over inlet pressure at nominal flow.

For the check out of the electronic and the valve assemblies in failure case tests have been performed to demonstrate that also in case of a failure in one circuit (switching to the redundant regulation circuit due to failure like leakage) the accuracy is within the defined tolerance.

A typical plot is shown in figure 6-4.

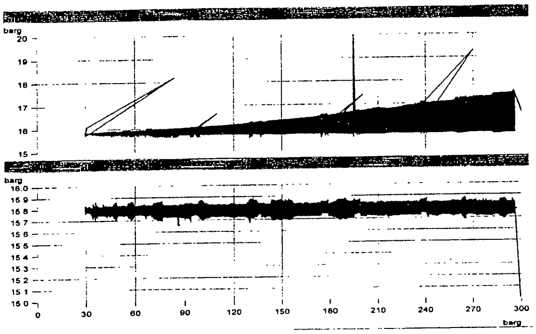

Figure 6-4 : Regulation behaviour using redundant circuit

Summary of development results :

Based on all the investigations and tests performed during this baseline development all necessary data and results are available for the definition of the final flight design.

7. Further Proceeding

The aim of the further proceeding at Astrium GmbH is to present during the year 2001 a full qualified Electronic Pressure Regulator Assembly for the application on chemical and electrical propulsion systems.

In order to meet this internal definition the future proceeding is already decided as follows :

- Establishment of final specification of common specification for EPR Assembly application on electrical and chemical propulsion systems
- Establishment of procurement specifications for supplied parts/units
- Finalisation of Development Plan
- Freezing of drawing set and relevant processes
- Manufacture and assembly hardware acc. the defined drawings and processes
- Perform final layout of electronic circuit
- Manufacture electronic circuit using commercial parts, but make sure these parts are available in high rel.
- Implement design assurance activities
- Establish Qualification Test Plan
- Perform Pre-Qualification
- **Perform CDR**
- Release manufacturing of QM Model
- Perform Final Qualification
- Perform Final Qualification Review
- Start manufacturing and testing of FM units