# Advanced fluidic components for Electric and Cold Gas Propulsion applications: review of status of achievements at TAS-I Florence

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**Abstract: Electric Propulsion (Ion and Hall) and Cold Gas Propulsion are currently being selected for a variety of space missions on Telecom, Remote Sensing and Science satellites. Both Electric Propulsion (EP) and Cold Gas Propulsion (CGP) rely on similar fluidic components that are dedicated to the propellant management and conditioning and thrust actuation. TAS-I Florence Site (former Proel Tecnologie) is consolidating and qualifying innovative fluidic components, such as High Pressure Regulation and Insulation Valve (HP RIV), Low Pressure Regulation Valve (LP RV), Low Pressure Regulation Valve with built-in nozzle (LP RVN)(only for CGP applications) and Mass Flow Sensor (MFS). The paper presents the status of achievements with reference to the above mentioned components, highlighting the qualification aspects for both EP and CGP applications. A review of performed test campaigns and relevant test results is, as well, presented and discussed versus the identified application perspectives. The achieved results demonstrate the full viability of the developed components and relevant technology readiness in view of applications "transversal" to different kind of satellite propulsion systems (in primis EP and CGP, and most likely Chemical Propulsion)**

## Nomenclature

*ASI* = Agenzia Spaziale Italiana (Italian Space Agency)
*CGP* = Cold Gas Propulsion
*CP* = Chemical Propulsion
*DSMC* = Direct Simulation Monte Carlo
*EP* = Electric Propulsion
*ESA* = European Space Agency
*FRS* = Flow Regulation Stage
*GIE* = Gridded ion Engine
*GEO* = Geostationary Earth Orbit
*HET* = Hall effect Thruster
*HP RIV* = High Pressure Regulation & Insulation Valve
*LP RV* = Low Pressure Regulation Valve
*LP RVN* = Low Pressure Regulation Valve with built-in nozzle (only for CGP applications)

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*MFS* = Mass Flow Sensor
*PFCU* = Propellant Flow Control & Conditioning Unit
*PRS* = Pressure Regulation stage
*PT* = Pressure Transducer
*TA* = Thrust Actuator
*TAS-I* = Thales Alenia Space Italia
*TAS-I FI* = Thales Alenia Space Italia, Florence Site (former LABEN Proel Tecnologie Division)
*TV* = Thruster Valve

## I. Introduction

EP (GIE and HET) and CGP are currently baselined for a remarkable variety of space missions on Telecom, Remote Sensing and Science satellites, used in stand-alone and in constellation or Formation-Flying configurations. Propulsion applications cover a wide range of maneuvers/tasks that span from orbit transfer/orbit acquisition to interplanetary cruising and up to the very fine control of the spacecraft attitude, positioning and pointing. Moreover, missions based on satellite systems in Formation Flying often ask very challenging requirements in terms of actuation of the satellite mutual position control. Among the various applications that are currently under assessment, development, or implementation within the European scenario we would like to mention Alphabus/Alphasat, Bepi Colombo, Small GEO platform, Darwin where Electric Propulsion is baselined and Gaia, Proba-3 Symbol-X and Nanoform (this latter a new mission sponsored by ASI) for which CGP will be most likely preferred. In particular for GAIA, the CGP has been already selected and currently under implementation

Both EP and CGP rely on similar fluidic components that are dedicated to the propellant management and conditioning (pressure and flow regulation) for producing the desired thrust, starting from the high pressure tank, where propellant is embarked and properly stored.

In particular for the EP the Propellant Flow Control /Conditioning Unit (PFCU) is identified as a potential area for improving the overall performances of new generation propulsion systems. New EP mission profiles ask for challenging features on the PFCU (e.g. variable flow with real time actuation, capability to operate with different EP technologies, modular conceptions/architectures, reduced mass, sizes, power consumption and recurring production costs together with a high components reliability).

For what concerns CGP, especially if used for generating thrust levels significantly lower than 1 mN (like in the GAIA application), the very finely controllable, reproducible and proportional regulation of the mass flow at the inlet of the Thrust Actuation valve is a real "must" for obtaining micro thrusts with the desired precision, stability, resolution and dynamic characteristics.

In this context TAS-I FI is directly involved in the design finalization and production of innovative fluidic components, namely:

- High Pressure Regulation and Insulation valve (HP RIV)
- Low Pressure Regulation Valve (LP RV)
- Low Pressure Regulation Valve with built-in nozzle (LP RVN)(only for CGP applications), also identified as Thruster Valve (TV)
- Mass Flow Sensor (MFS)

The technology consolidation and qualification of the above mentioned fluidic components is currently underway in the framework of 2 important European programs respectively in the Telecom and Science application fields:

- Alphabus (ARTES 8 contract, funded by ASI), for what concern EP applications on GEO satellites
- GAIA (EADS Astrium GmbH/ESA contract) for the Cold Gas Micro Propulsion System dedicated to the spacecraft fine orbit control.

In the following a presentation of the status of achievements in this field is presented in detail.

## II. High Pressure Regulation and Insulation Valve (HP RIV)

The HP RIV component features the actuation, in a very fine and fully analog way, of the gas (propellant) mass flow through the valve body. The HP RIV exit orifice opening is adjusted by an actuation mechanism based on a stack of piezo-electric disks powered by a "low voltage" bias signal. A metallic plunger, mechanically coupled to the piezo-stack, is moved as a consequence of the piezo-stack voltage bias along the valve axis, thus regulating the actual open area of the exit orifice in a progressive, analog way.

The main HP RIV features are here below summarized:

- Direct Interfaceability to the high pressure tank (up to value higher than 300 bar)
- Normally closed when de-energized, performing insulation from the high pressure in the tank
- Compatibility with a variety of gases such as Xe, $N_2$, Ar, Kr, He
- Operation in closed loop control in conjunction with different sensing elements:
  - o Pressure Transducer for the actuation of a pressure regulation strategy
  - o Mass Flow sensor for the actuation of a mass flow regulation strategy
  - o Discharge/beam current sensor as well for the actuation of a mass flow regulation strategy
- Fully analog operation with an extremely low noise

The main elements/parts composing the HP RIV (see also Figs. 1, 2 and 3) are:

- Piezo ceramic actuator stack (or disk benders) made with a multi-layer ceramic technology
- Antagonist S-shaped spring (made with an electro-erosion process)
- Piezo-actuator "return" spring
- Plunger or shutter (made with Ti and kept in the axis of the valve by means of two springs located at two opposite ends of the plunger itself)
- Orifice
- Xe heating provisions (necessary only for operation with Xe at an inlet pressure higher than 40-50 bar)
- Electric interface
- Mechanical housing (made with a Ti alloy): bottom cover cap joined to the cylindrical structure by plasma welding process
- Gas Inlet and outlet pipeline: Kovar tubes brazed to the cap (inlet side) and to the Valve body (outlet side)

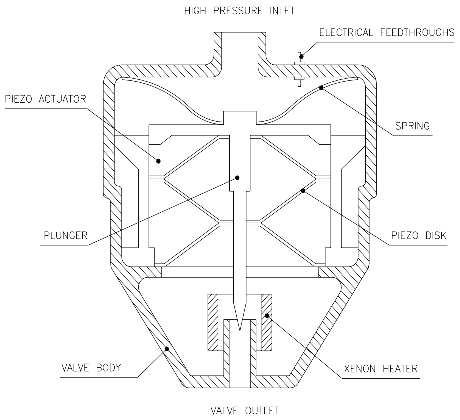


**Fig. 1 Conceptual operation mechanism of the HP RIV and relevant main components**

**Fig. 2 HP EM Model**

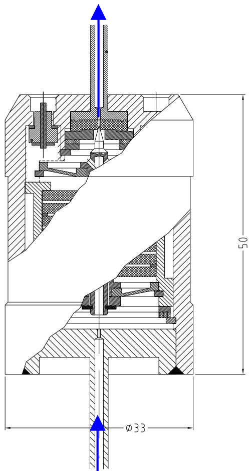


**Fig. 3: Cross Section of the HP RIV EM**

The piezo actuator is accommodated in the high pressure side, thus the high pressure helps the spring when the valve is de-energized (closed). A suitable dimensioning of actuator force in respect of the high pressure + spring force allows smooth valve opening and operation. 2 HP RIV Models are currently addressed:

- HP RIV without heater for operation with $N_2$ and Xe at a pressure lower than 40-50 bar.
- HP RIV with built-in heater for operation with Xe at a pressure higher than 40-50 bar.

The heating of Xe at high pressure is needed for avoiding flow and pressure instabilities connected to partial Xe freezing during the expansion process. The instabilities may be overcome by giving enough thermal power to the gas, both upstream and immediately downstream the orifice: in this way the expansion of the gas starts at a higher temperature and continues following a curve intermediate between the isentropic (the worse case) and the isothermal.

Currently a HP RIV EQM model is being developed at TAS-I FI Site for application within the pressure Regulation Stage of a Xe PFCU. The new HP RIV will implement:

- New configuration based on piezo-ceramic stacks
- Re-engineered housing
- Upgraded heating provisions for avoiding Xe freezing at high pressure (> 40 bar)
- Strengthen S-shaped spring to prevent slight valve opening and therefore leak under vibration environment (this situation is experienced during launch).

In the new design the heating provision is implemented accommodating in the valve body 3 heaters connected in series.

The HP RIV body, in order to achieve operating pressure of 150 bar and higher (and related proof and burst pressures) has been miniaturized. In fact a reduced piezo-actuator diameter and thus valve body will increase the valve high pressure withstanding capability, while exhibiting savings on mass and dimensions.

The new actuator configuration foresees the use of 2 separate piezo-stacks:

- Base stack (31 mm height)
- Regulation stack (33 mm height)

The new HP RIV cross section drawing is shown in Fig. 4. In Fig. 5 the results, in graphical form, of the mechanical analysis performed on the S-shaped spring are presented.

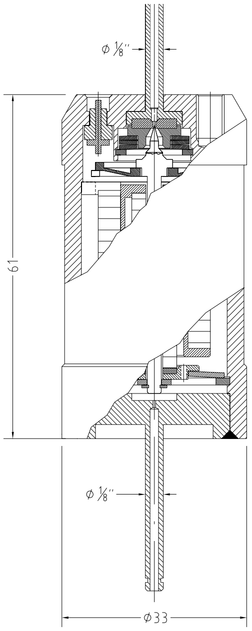


**Fig. 4: New HP RIV Design**

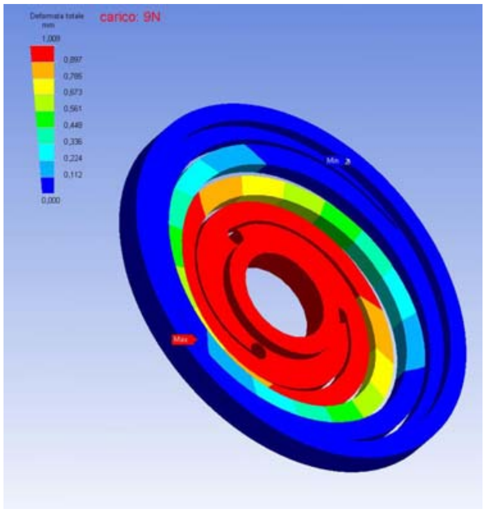


**Fig. 5: Strain Distribution on the S shaped spring within the HP RIV**

A dedicated fluid dynamic modelization has been used for the validation of the new HP RIV design.

Table 1 below summarizes the possible application contexts of the HP RIV

| HP RV Application scenario | Nominal operating gas | Operation in closed loop with | Special provisions to be adopted | Notes |
|---|---|---|---|---|
| PRS of an EP PFCU | Xe | Low Pressure Transducer | Heating Provision when operated with Xe | Pressure reduced and stabilized at a value generally of few bar |
| Direct Flow Regulation from high pressure within an EP PFCU | Xe | Mass Flow Sensor | Heating Provision when operated with Xe | Flow regulated in order to achieve the desired mass flow set point |
| Direct Flow Regulation from high pressure within an EP PFCU | Xe | Discharge Current Sensor (HET EP) or Beam Current Sensor (GIE EP) | Heating Provision when operated with Xe | Flow regulated in order to achieve the desired discharge current or Beam Current |
| PRS of a CGP system | $N_2$ | Low Pressure Transducer | None | Pressure reduced and stabilized at a value generally of few bar |
| PRS for a Pressurizing Gas within a CP System | He | Low/Medium Pressure Transducer | None | Pressure reduced and stabilized at a value generally of few tens of bar |

**Tab. 1 Overview of possible application scenarios for the HP RIV developed at TAS-I FI**

## III. LP RV and LP RVN

The LP RV (see Figs. 6 and 7) is quite similar to the above described HP RIV. Its body is made lighter as the assumed inlet pressure is not exceeding few tens of bars (nominally it stays around few bars). Either the LP RV is operating with Xe or with $N_2$ the LP RV does not need any heating provision for avoiding gas freezing and thus anomalous

The LP RV design provides isolation against low pressure with low leakage, and allows tight – analog – control of the propellant flow during operation, thanks to the advantages provided by piezo- technology. The piezo-actuator power consumption is very low (< 100 mW) and the design is compact and lightweight.

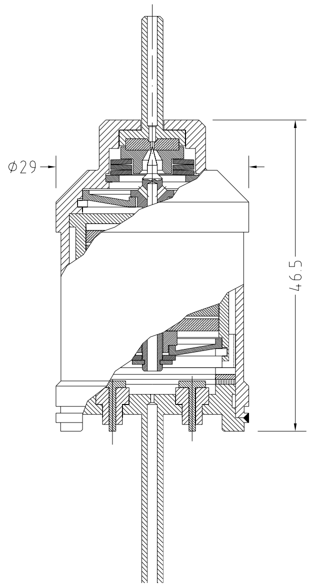


**Fig. 6: LP RV Cross section drawing**

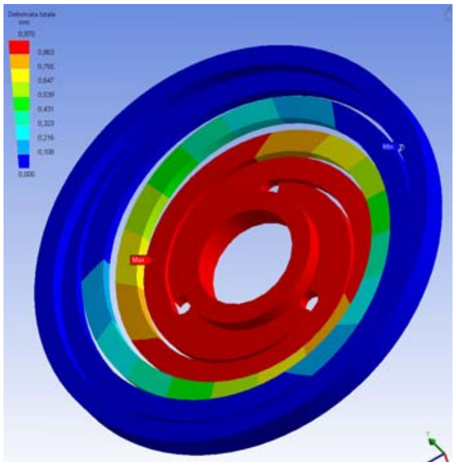


**Fig. 7: Strain Distribution on the S-shaped spring within the LP RV**

For the CGP application a modified version of the LP RV has been developed, engineered and pre-qualified. This version of the LP RV is identified as LP RVN or TV (Thruster Valve). The LP RVN Engineered model is shown in Fig. 8 and 9 below. In the LP RVN a micro-nozzle (see Fig. 10) is realized through an electro-erosion process and integrated in the valve body, downstream the exit orifice. This modification has the purpose of implementing a provision for allowing the propellant gas (nominally $N_2$ in the case of a CGP thrust actuator) expansion in order to generate a thrust. The LP PVN used as Thrust actuator within a CGP operates in conjunction with a MFS (see after) placed upstream the LP RVN. This configuration is the baseline one adopted for the CGP Thrust Actuation Stage of the GAIA program

**Fig. 8: LP RVN Engineered Model**

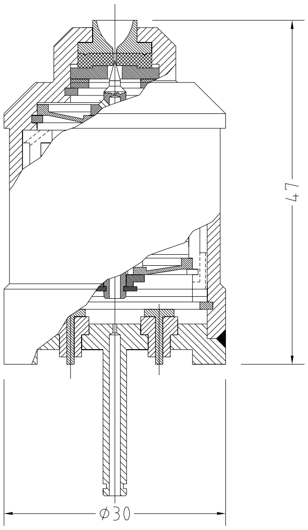


**Fig. 9: LP RVN Cross section**

**Fig. 10: LP RVN Nozzle (cutaway) close up**

The LP RVN nozzle has been designed and validated also through a dedicated computer modelization and simulation (see Figs. 11 and 12 here below). The implemented numerical code is a DSMC code based on routines by G.A. Bird. The program employs collision and sampling cells which automatically adapt to the flow density in order to obtain near uniform numbers of molecules per cell; The flow profile into the LP RVN has been obtained through the use of a rarefied-gas model in the nozzle expansion region.

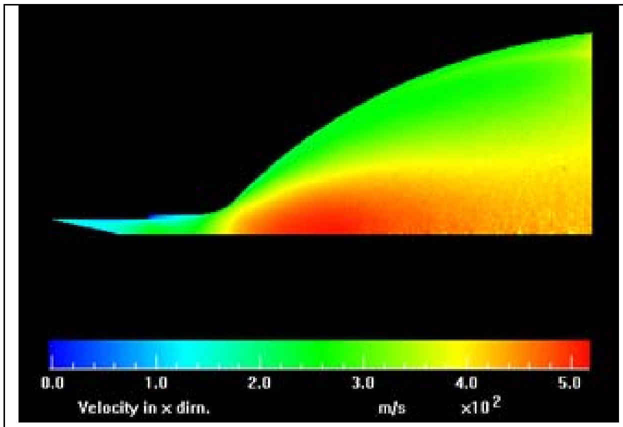


**Fig. 11: Simulation of the velocity distribution at the nozzle exit**

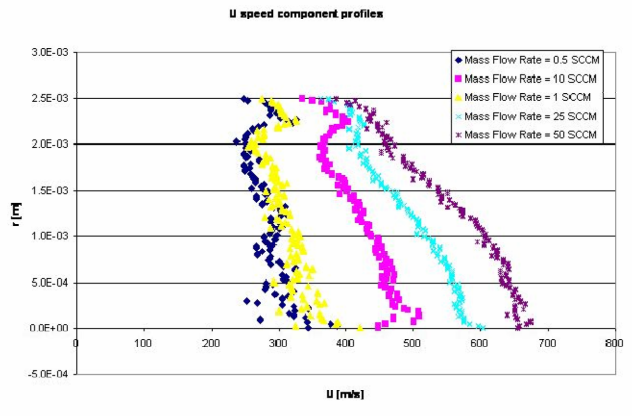


**Fig. 12: Axial velocity component profiles at the exit section, nominal conditions, at different $\dot{m}$**

The new LP RVN design, selected for the realization of the CGP TA of GAIA mission, implements a special provision for the compensation of the parasitic thrust related to actuator movements when the TA is commanded with on-off or with thrust level change sequences. The new design (see Fig. 13) includes a set of 2 additional "compensation" piezo-disks with a spring and an added mass; these items are just "passive elements" and are not part of the actuator which remains the baseline one. The valve body is slightly enlarged in order to host the additional parts.

The reason why in the new design we add 2 "compensation" piezo-disks only is that in the actuator design only 2 piezo-disks are in charge to perform the mass flow throttling and on-off task, whilst the remaining 5 piezo-disks are kept at a fixed biasing. The fixed biasing is applied/removed at beginning/end of an operating session (of any duration). Thus the actuator mass to be compensated is actually related to two piezo-disks + plunger + part of spring. The mechanical and electrical arrangement is such that the compensation disks produce a displacement opposite to the actuator one. Fig. 14 shows the Prototype of the new LP RVN (or TV) for the CGP on GAIA.

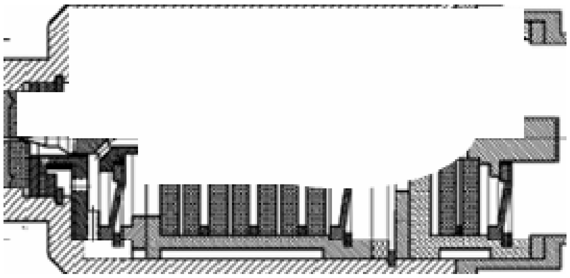


**Fig. 13: Cross section view of the new LP RVN new design conceived for compensation of actuator moving mass**

**Fig. 14: Prototype of the LP RVN new design implementing the parasitic noise compensation solution**

Table 2 below summarizes the possible application contexts of the LP RV/RVN.

| LP RV/RVN Application scenario | Nominal operating gas | Operation in closed loop with | Special provisions to be adopted | Notes |
|---|---|---|---|---|
| Flow Regulation from a reference low pressure within an EP PFCU | Xe | MFS placed downstream the LP RV valve | None | Flow regulated in order to achieve the desired mass flow set point |
| Flow Regulation from a reference low pressure within an EP PFCU | Xe | Discharge Current Sensor (HET EP) or Beam Current Sensor (GIE EP) | None | Flow regulated in order to achieve the desired discharge current or Beam Current set point |
| TA of a CGP system | $N_2$ | MFS, placed upstream the LP RVN valve | Implementation of parasitic noise compensation by adding "passive" piezo- disks | Flow regulated in order to achieve the desired (commanded) Thrust level |

**Tab. 2: Summary of application scenarios for the LP RV/RVN developed at TAS-I FI**

## IV. MFS

The MFS is a fundamental component of both an EP and CGP fluidic conditioning equipment. It is used to measure/monitor the actual mass flow rate flowing through this device which is placed in series to the Flow Control actuator. The MFS device developed by TAS-I the mass flow information is obtained from the measurement of the "temperature unbalance" that manifests in presence of the mass flow, between two thermometers, while a constant amount of power is provided in between. Substantially, the new MFS device is a differential calorimetric flow sensor which detects the heat amount transported by the fluid. Practically the heating power **W** can be theoretically related to the thermal unbalance $\mathbf{\Delta T= T_2 - T_1}$ through the simple relation: $\mathbf{W} = \dot{m}\ \mathbf{C_p \Delta T}$, being $\dot{m}$ the gas mass flow rate and $C_p$ the gas specific heat.

The MFS has been implemented in a Si Chip. A heating element is positioned in between the upstream and downstream temperature sensing elements (thermo-resistors) which are located on cantilever beams for **ΔT** detection. In addition, within the Si chip, two other temperature sensors are realized:

- the intermediate sensor for monitoring of bulk surface temperature
- the external sensor for the monitoring of the gas temperature

These additional temperature sensors have been added in the new MFS design to control the gas temperature at the MFS input. This solution will avoid any drift in the device response, as a consequence to temperature stabilization

The MFS silicon structure is packaged and bonded in an $Al_2O_3$ support, and a plastic cover is glued on top, providing a closed path for the gas flow (gas duct). The Si structure and the gas duct are coupled to a mechanical structure with welded inlet and exit pipe work. The whole assembly is hosted in a mechanical housing to provide mechanical protection, thermal control, fastening I/Fs, Front-end electronics integration.

The new MFS design (see Figs. 15, 16, 17 and 18) aims at:

- Covering a dynamic range of up 3 order of magnitude in the mass flow level detection
- Improving the device sensitivity and time response, by reducing the cross sectional area for the mass flow, which is now concentrated on the small Si structure and by increasing the resistance of the thermometers
- realizing a more rugged package able to withstand the environmental mechanical loads
- allowing operation with both $N_2$ and Xe gas.

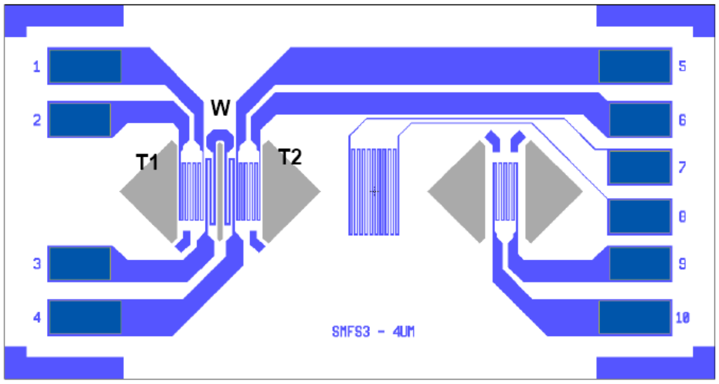


**Fig. 15: MFS implemented in a Si Chip (new layout)**

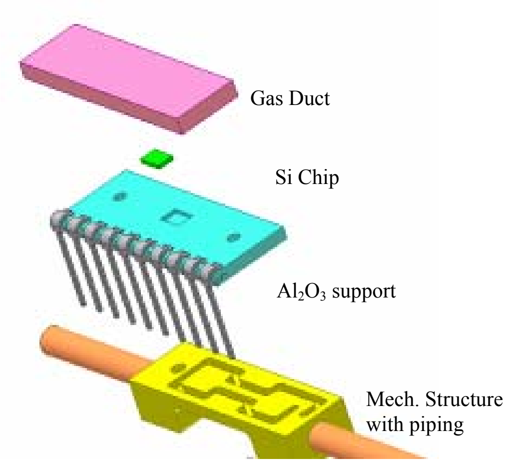


**Fig. 16: MFS main elements/parts**

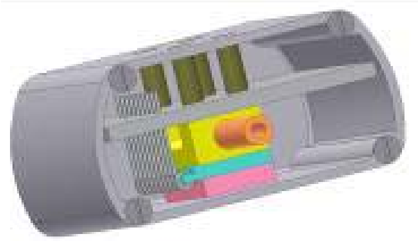


**Fig. 17: Schematic 3D view of the MFS internal structure**

**Fig. 18: 3D view of the assembled new MFS**

When operated within an EP PFCU the MFS is placed downstream the LP RV (or HP RIV, in the case where the flow control is implemented in a single stage starting directly from the high pressure in the tank). When operated within a TA of a CGP system the MFS is placed just upstream the LP RVN.

## V. Fluidic Components performance overview

This paragraph presents, in summary (see Tab. 3 below) the reference features associated to the above presented components. Many of these features/performances have been already verified throughout dedicated test campaign at component level carried out on EM versions of the mentioned components.

| ***Feature/parameter*** | ***HP RV*** | ***LP RV /RVN*** | ***MFS*** |
|---|---|---|---|
| Design/Configuration | All welded | | All welded |
| Actuating/sensing Element | Piezo-ceramic stacks | Piezo-ceramic ring-benders (disks) | Si Chip featuring a differential calorimeter concept |
| Inlet Pressure | | | |
| • Nominal Operating (MEOP) | 150 (Xe) or 300 bar ($N_2$) | 0 – 5 bar abs | 0 – 2 bar abs |
| • Proof | 300 (Xe) or 600 bar ($N_2$) | 10 bar abs | 4 bar abs |
| • Burst | 600 (Xe) or 1200 bar ($N_2$) | 20 bar abs | 8 bar abs |
| Leakage<br>• Internal @ nom. inlet pressure<br>• Extern. @ nominal inlet pressure | $5x10^{-7}$ sccs GHe (at 150 bar) | $5x10^{-7}$ sccs GHe (at 5 bar) | $< 10^{-7}$ sccs GHe |
| Flow rate @ nominal inlet pressure | 0-100 mg/s | 0-50 mg/sec | 2 ranges<br>CG 0.002÷2 mg/s<br>EP 0.05-50 mg/s |
| Mass & Dimensions | | | |
| • Width | $\phi$33 mm | ϕ 30 mm | 34 mm |
| • Length | 60 mm | 47 mm | 57 mm |
| • Thickness | NA | NA | 17 mm |
| • Mass | 180 g | 150 g | 90 g |
| Power Consumption | < 0.1 W<br>< 7 W operating with Xe | < 0.1 W | Few mW |
| Time response | < 100 ms | < 100 ms | ≈10 ms |
| Sensitivity | NA | NA | < 0.1 scc/min (expected) |

**Tab.3 Summary prospect of performances/features associated to the developed fluidic components.**

## VI. Fluidic Components applications schemes

In this paragraph the possible application configurations of the developed components are addressed with reference to the 2 main applications fields (EP and CGP).

A general reference scheme for the application of the fluidic components within an EP PFCU is sketched in Fig. 19. This configuration refers to the most common architecture currently adopted in many EP applications (e.g. BepiColombo and Alphabus) where there is an upstream PRS for reducing the pressure and a downstream low pressure FRS.

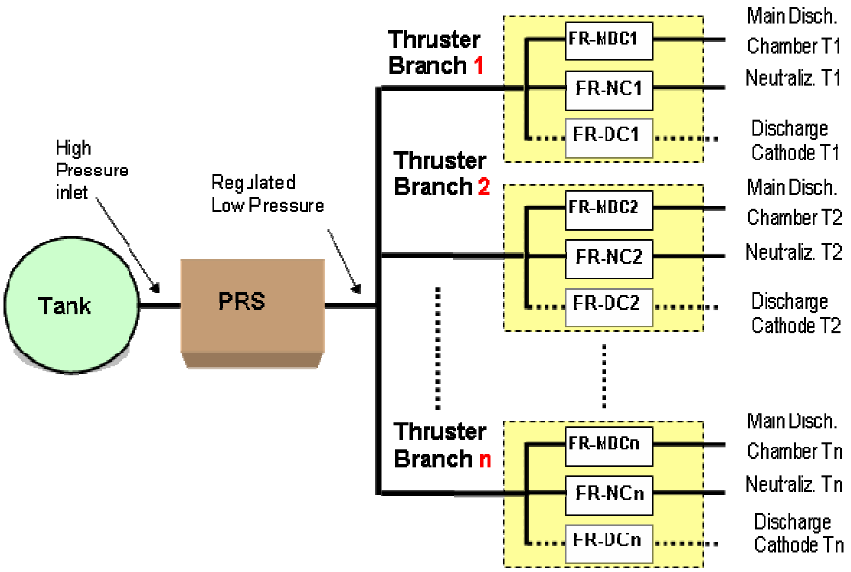
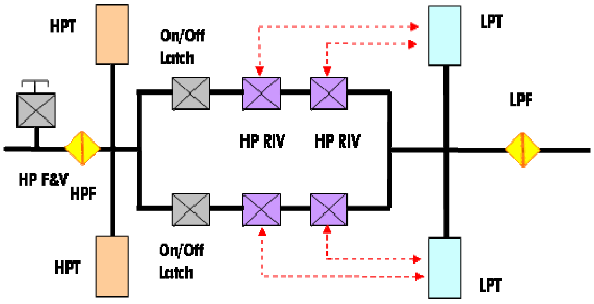


**Fig. 19: General architecture/configuration of a PFCU for an EP system**

Figs. 20 and 21 below shows the possible reference architecture adopted for the PRS and FRS assemblies. Within each block the presence of the developed fluidic components is well identified.



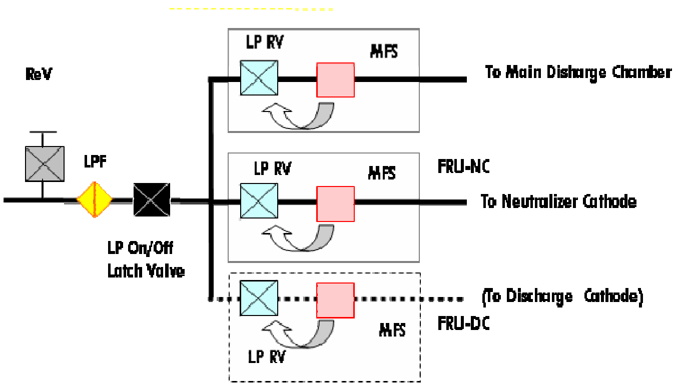


**Fig. 20: PRS architecture for an EP PFCU System** **Fig. 21: FRS architecture for an EP PFCU**

Figures below show the assemblies at prototype level realized for the PRS (Figs. 22 and 23) and for the FRS (Figs. 24 and 25).

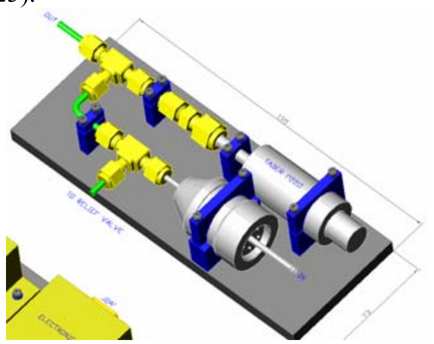


**Fig. 22: 3D configuration layout of PRS section (lab. Realization)**

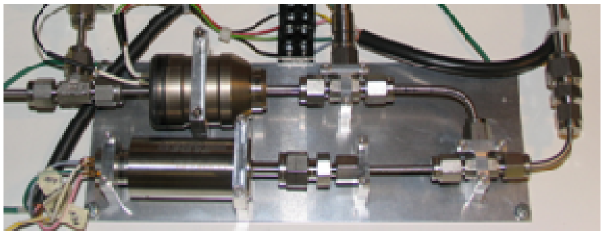


**Fig. 23: photo of the PRS prototype**

**Fig. 24: 3D configuration layout of FRS section (lab. Realization)**

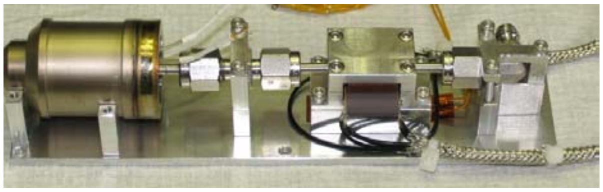


**Fig. 25: photo of the FRS prototype**

For a CGP application the PRS is quite similar to the EP one. In a CGP the TA is realized (see Fig. 26) by adopting a LP RVN operating in closed loop control with a MFS (positioned upstream the LP RVN or TV).

The new TA configuration under manufacturing for GAIA foresees the realization of a dedicated Thruster package (see Fig. 27) including:

- Mechanical Housing and inlet pipeline
- Inlet Low Pressure Filter
- MFS
- LP RVN
- MFS Front End electronics & Electrical connectors (x 2)
- Thermal Conditioning of the MFS and Front end electronics
- Internal Pipe work

Figure below shows the Components arrangement for The TA's in a CGP system and a 3D sketch of the TA package.

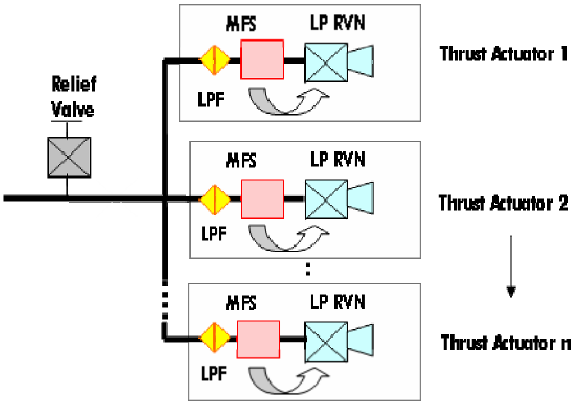


**Fig. 26: TA section of a CGP system**

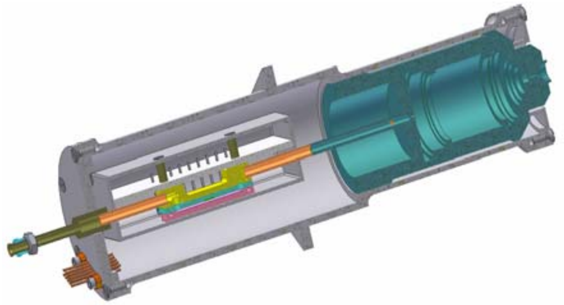


**Fig. 27: Layout of a single TA integrating a LP RVN and a MFS**

## VII. Qualification Activities overview

In this paragraph we address the set of parameters to be verified within the qualification test at assembly level with reference to the 2 mentioned parallel programs respectively dedicated to EP and CGP applications.

We have identified for qualification purposes 3 main assemblies, each of them including as a minimum 2 of the fluidic components presented and described in the previous sections. These assemblies are:

- PRS: containing for qualification purposes 2 HP RIV (the one upstream can act also as an on/off valve) operating in closed loop with a Low Pressure Transducer (Off the shelf component externally procured)
- FRS: containing for qualification purposes a LP RV operating in closed loop with a MFS
- TA: containing for qualification purposes a LP RVN operating in closed loop with a MFS to obtain a micro-thrust

|  | **PRS** | **FRS** | **TA** | Notes |
|---|---|---|---|---|
| Application | **EP** | **EP** | **CGP** |  |
| Configuration | HP RIV in closed loop with a PT | LP RV in closed loop with MFS | LP RVN in closed loop with MFS |  |
| Program | ARTES 8/Alphabus | ARTES 8/Alphabus | GAIA | Ref. for qualification |
| Operating Gas | Xe | Xe | $N_2$ | Compatibility with He, Ar, Kr |
| Physical Properties | Target Mass < 1kg | Target mass < 500 g | Target Mass 300 g | Referred to a non redundant configuration |
| Inlet Pressure Range | 140-200 bar (nom.150 bar) | 1-3 bar (nom. 2 bar) | 1-2 bar | Nominal Value |
| Proof | 300 bar | 4 bar | 4 bar | Verified at single component level; to be verified on EQM Ass.y |
| Burst | 600 bar | 8 bar | 8 bar |  |
| Regulated parameter range | Pressure: 1 to 3 bar, nominal 2 bar, from a nominal inlet pressure of 150 bar of Xe | Mass Flow: 0.05 to 50 mg/s, starting from a nominal inlet pressure of 2 bar | Mass Flow: 0.002 to 1 mg/s of $N_2$ correspond to a thrust regulation in a range: 1 to 500 µN | To be verified by test on EQM, already verified on EM assemblies |
| Mass Flow range | 0 to 100 mg/s of Xe | 0 to 50 mg/s of Xe | 0 to 1 mg/s of $N_2$ | verified |
| Regulated parameter resolution | 0.05 bar | 0.05 mg/sec | <0.002 mg/sec of $N_2$ corresponding to a thrust < 1 µN |  |
| Regulated parameter accuracy | +/- 5% FS (goal 2%) | +/- 2% FS | +/- 2% FS | FS= Full Scale |
| Regulated parameter sensitivity | 0.05 bar (TBC) | 0.05 mg/sec | <0.002 mg/sec of $N_2$ corresponding to a thrust < 1 µN |  |
| Internal leakage | < 5x10$^{-6}$ sccs (GHe) | < 1x10$^{-6}$ sccs (GHe) | < 1x10$^{-6}$ sccs (GHe) |  |
| External leakage | < 5x10$^{-6}$ sccs (GHe) | < 1x10$^{-6}$ sccs (GHe) | < 1x10$^{-6}$ sccs (GHe) |  |
| Power Consumption (steady-state) | < 10 W | < 1W | <1W | PRS with HP RIV equipped with heater/s |
| Time response | < 100 ms | < 100 ms | up to 8Hz | At 63 of the new commanded parameter level |
| Noise in the regulated parameter | 0.01 bar/√Hz (to be confirmed by test) | 0.001 mg/s/√Hz | 1 µN /√Hz (1mHz-1Hz);<br>0.045µN /√Hz (1-150 Hz) | Evaluated on a TA prototype. Improved results are expected from the new version of TA |
| Operat. Temperature | +17 to + 95°C | +17 to + 95°C | -20 to + 50°C |  |
| Lifetime | 20000 h | 20000 h | 20000 h | Under verification |
| No. of on/off cycles achievable | > 100 million | > 100 million | > 500 million | Already tested for the PRS and FRS with $N_2$; Test ongoing for the TA (350 million achieved) |
| Pipe work I/F | 1/8” Ti Alloy | 1/8” Ti Alloy | 1/8” Ti Alloy |  |
| Mechanical Environment | Alphabus specification | Alphabus specification | GAIA specifications |  |

**Tab. 4: Overview of reference performance /features asked for PRS, FRS and TA qualification in the reference ESA programs**

## VIII. Conclusion

A set of innovative fluidic components (namely HP RIV, LP RV, LP RVN and MFS) has been presented and their technology /configuration overviewed. These basic components can be assembled in different configuration or architectures for addressing a variety of potential applications mainly in the EP and CGP fields. Technical specification (most of parameters have been already verified by dedicated experimental activities) of these components have been presented and discussed. Applications of assemblies (namely PRS FRS and TA) obtained by integration of the above mentioned components in suitable configurations are presented in both the EP and CGP areas. Finally an overview of the assemblies qualification program is introduced with reference to 2 important European Programs Alphabus/ARTES 8 and GAIA, respectively for the EP and CGP use finalization

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