SMA Valve for Propulsion Subsystem Passivation

Armin Herbertz
TEC-MPC

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Passivation Needs

At the end of mission the propulsion system contains some potential hazards:

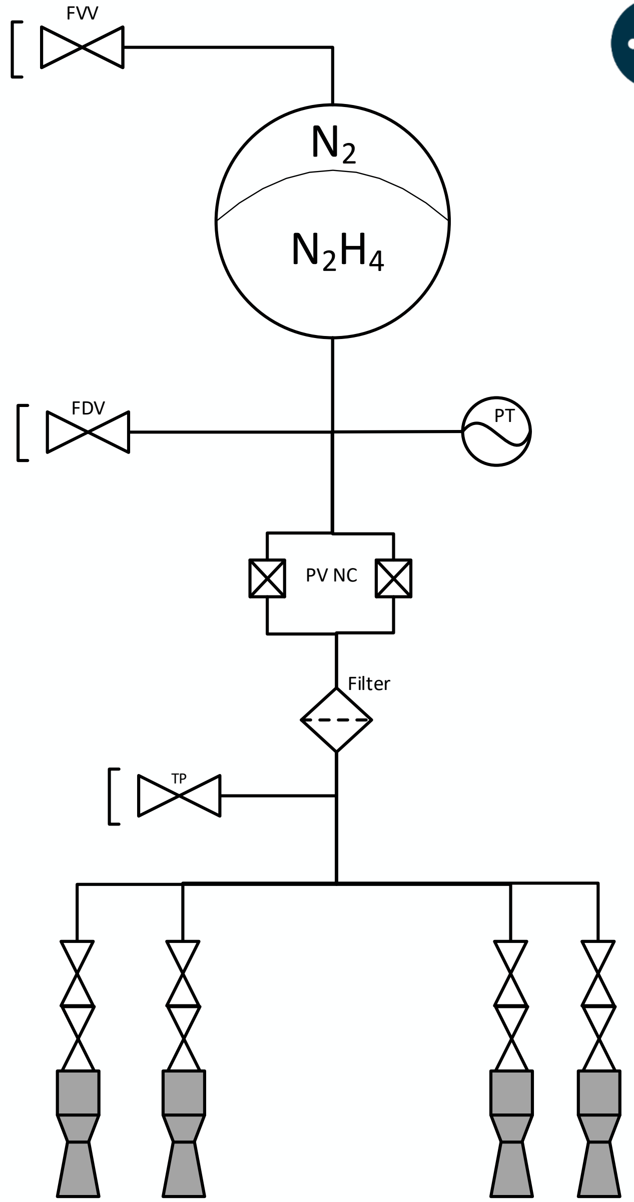
- Energetic propellants
- High pressure gas

Both have the potential in adverse situation to lead to an explosive event, which could create debris in orbit

--> Passivation foreseen to remove all fluids after end of mission.

Monopropellant System

- ➢Usually operated in “blow down” mode
- ➢Typical propellant: hydrazine (N_2H_4)
  - ➢ strict temperature control required
  - ➢ control of pressure shocks
- ➢Chemical reaction triggered by catalyst, to ensure uniform reaction, catalyst bed needs to be electrically heated
- ➢Often used in small spacecraft with limited Δv and thrust needs

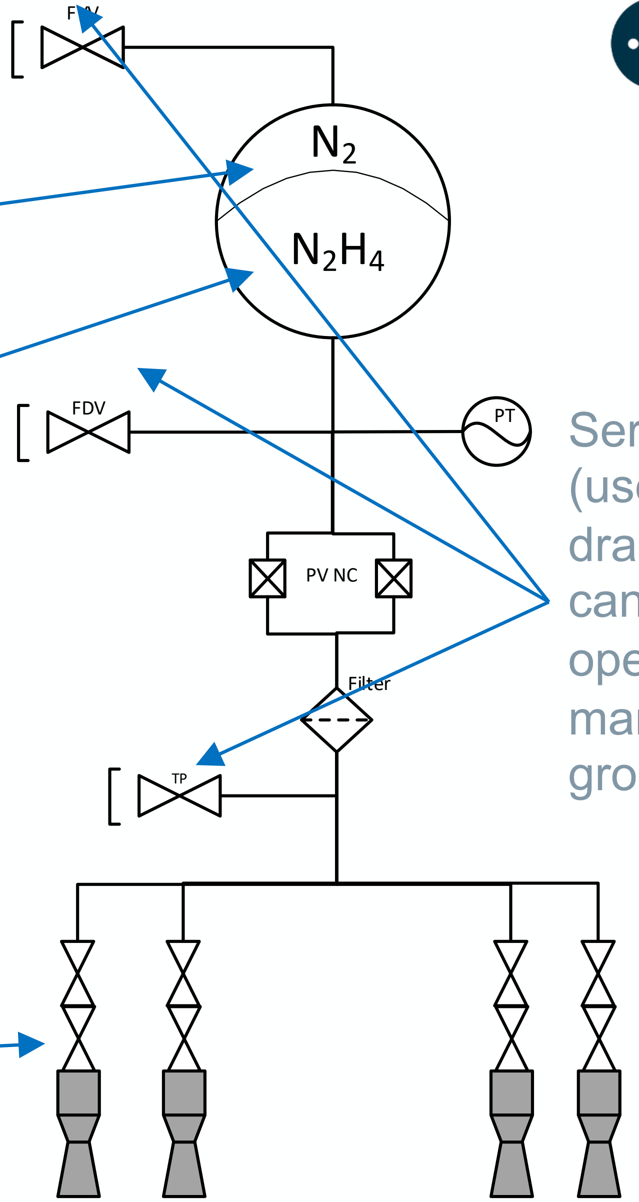


Monopropellant System

Pressurant
BOL ~22 bar
EOL ~5.5 bar

Energetic propellant, prone to thermal decomposition

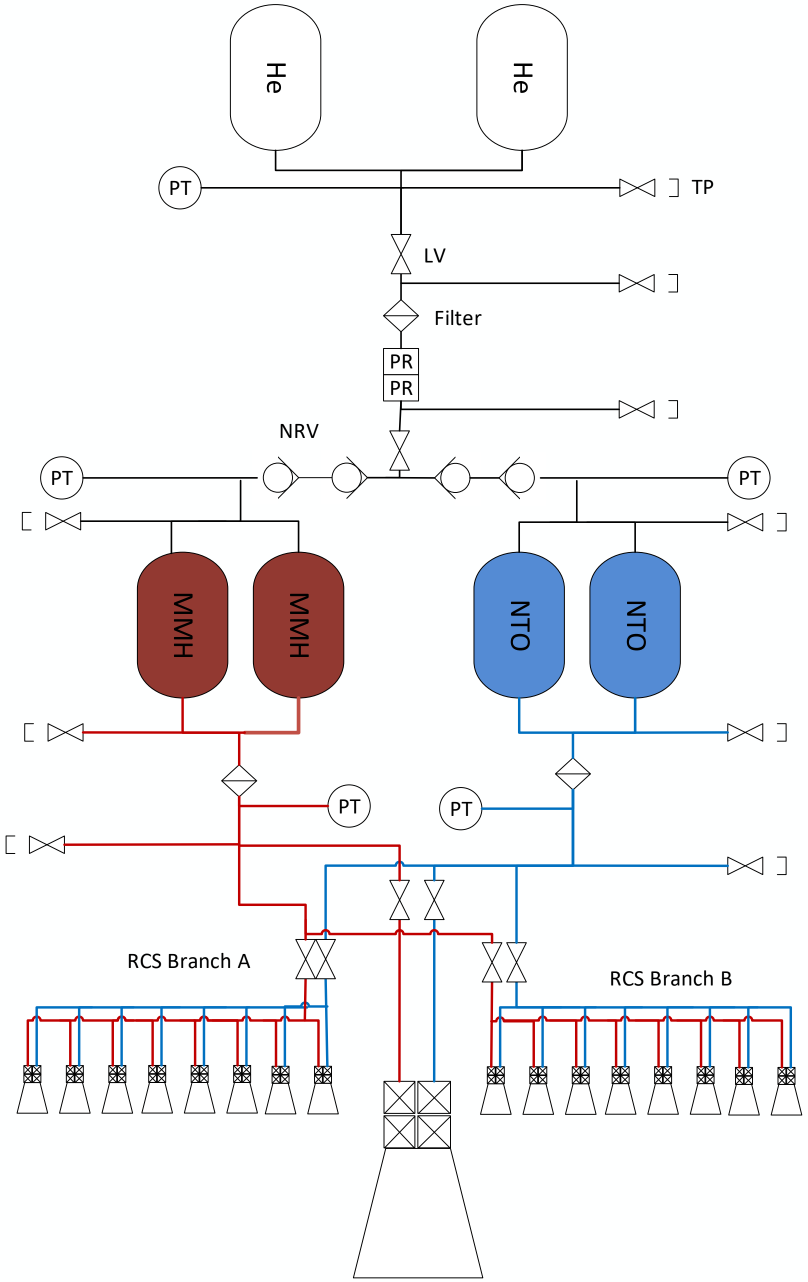
Thrusters (dual seat flow control valves) can be telecommanded



Service Valves (used for filling , draining, testing) can only be operated manually on ground

Bipropellant System

- ➢Usually operated in "pressure regulated" mode
- ➢Typical fuel: MMH (CH_6N_2)
- ➢Typical oxidizer: NTO (N_2O_4)
- ➢Hypergolicity of propellants requires extra care to prevent accidental mixing of propellants ahead of the combustion zone
- ➢Often used in spacecraft with large thrust need
- ➢Often used for both orbit insertion (apogee engine) and attitude control purposes (reaction control thrusters)



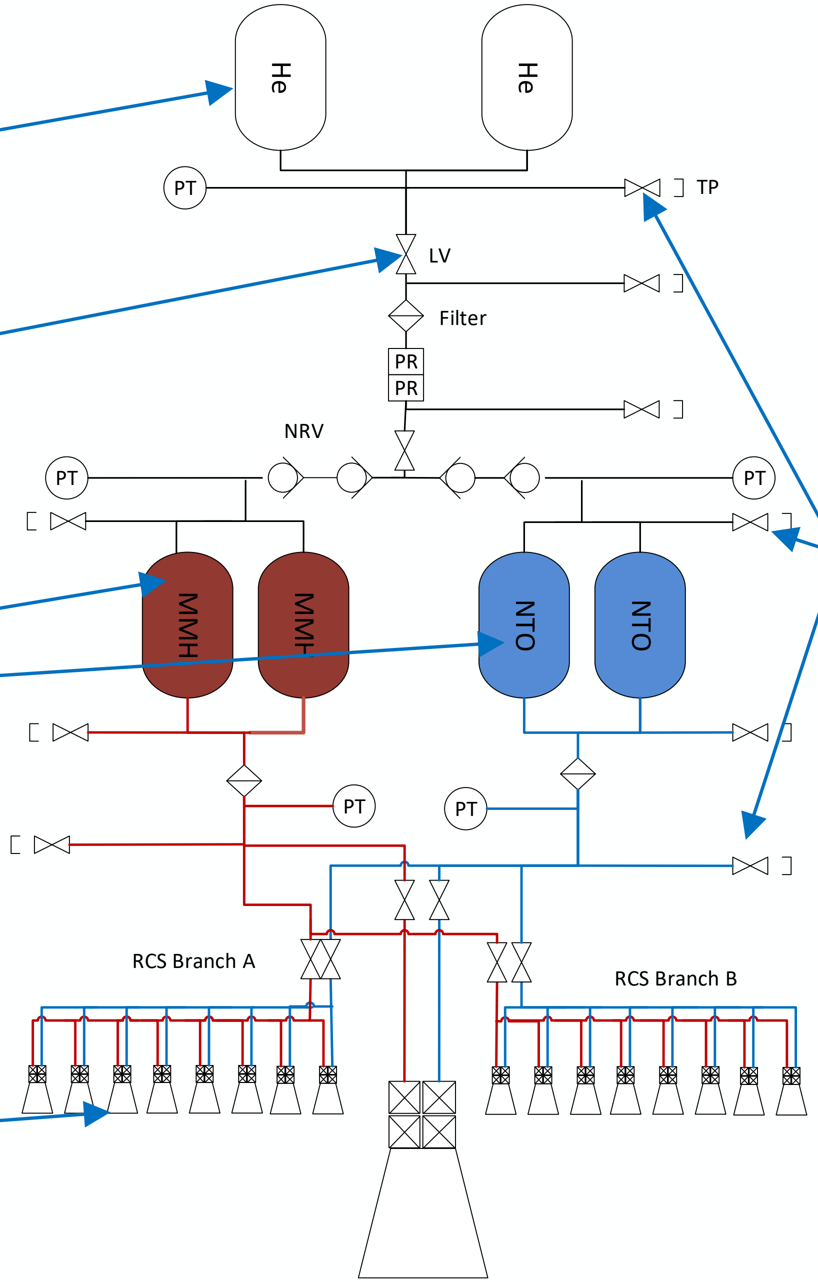
Bipropellant System

Pressurant at high pressure
BOL 200+ bar
EOL ~40 - 60 bar

High pressure section can typically be isolated by latch valves or pyrovalve ladders

Energetic bipropellant, reactive on mixing

Thrusters (dual flow control valves) can be telecommanded. However typically both fuel and oxidizer are linked and commanded at the same time

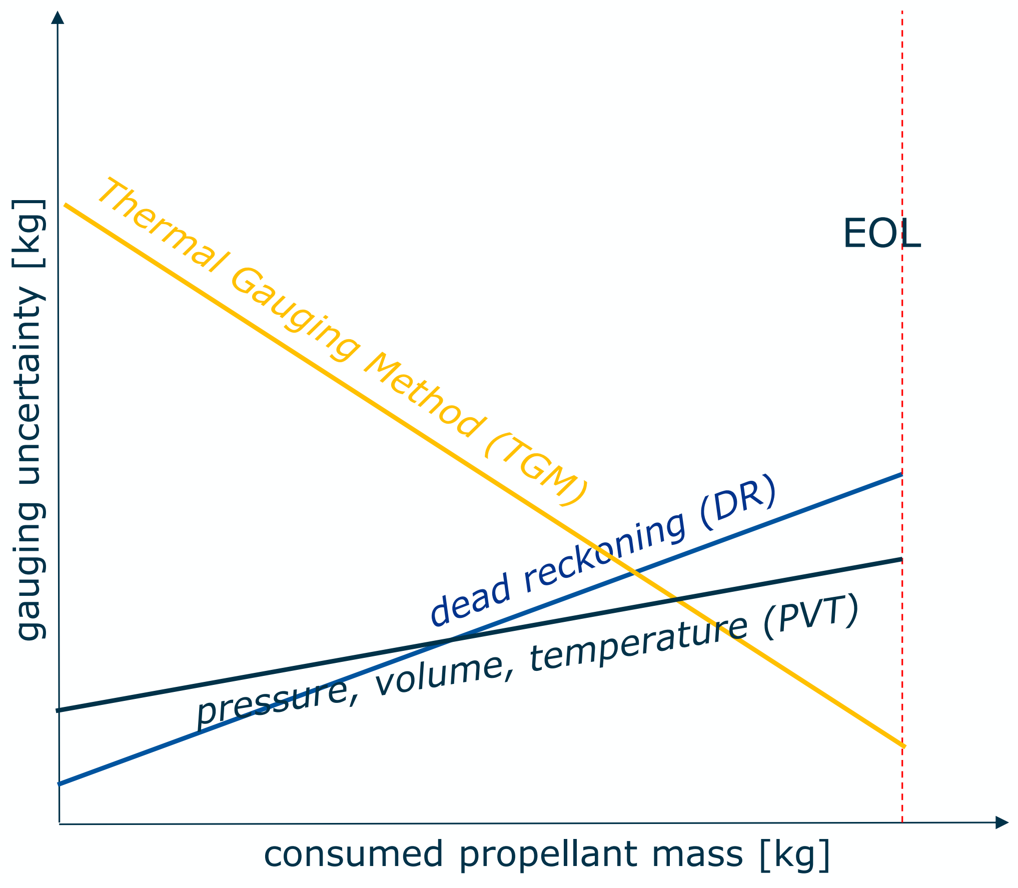


Service Valves (used for filling, draining, testing) can only be operated manually on ground

Gauging

Examples of actual gauging requirements:

- “Determination of remaining propellant masses shall be possible to accuracy either better than 1% of the propellant at launch or better than 3% of the propellant remaining, whatever is more accurate”
- “The Propulsion subsystem shall provide means for determination of the remaining propellant quantities with an accuracy to predict the end of the nominal operational life with 3 months accuracy.”
- "The spacecraft shall support propellant gauging such that the remaining propellant can be determined within 2.1 % (TBC) accuracy of the full tank capacity."
- “The non-usable propellant residuals and uncertainties in the complete Propulsion Subsystem at EOL shall be ≤ 36.4 kg.”



Residuals

➢Residuals are differentiated between **static** residuals and **dynamic** residuals

➢Static residuals are created by unusable propellant remaining in the feed system at EOL (e.g. in pipes, or depending on tank expulsion efficiency in tank). Typically 2% of nominal propellant load is considered static residuals

➢Dynamic residuals appear only in bipropellant systems. They are created by different thruster mixture ratio with respect to tank mixture ratio (especially relevant in systems with several types of thrusters, or even more so in dual mode systems). Dynamic residuals cover the cases where a system used up all fuel, while oxidizer (residuals) remains and vice versa.

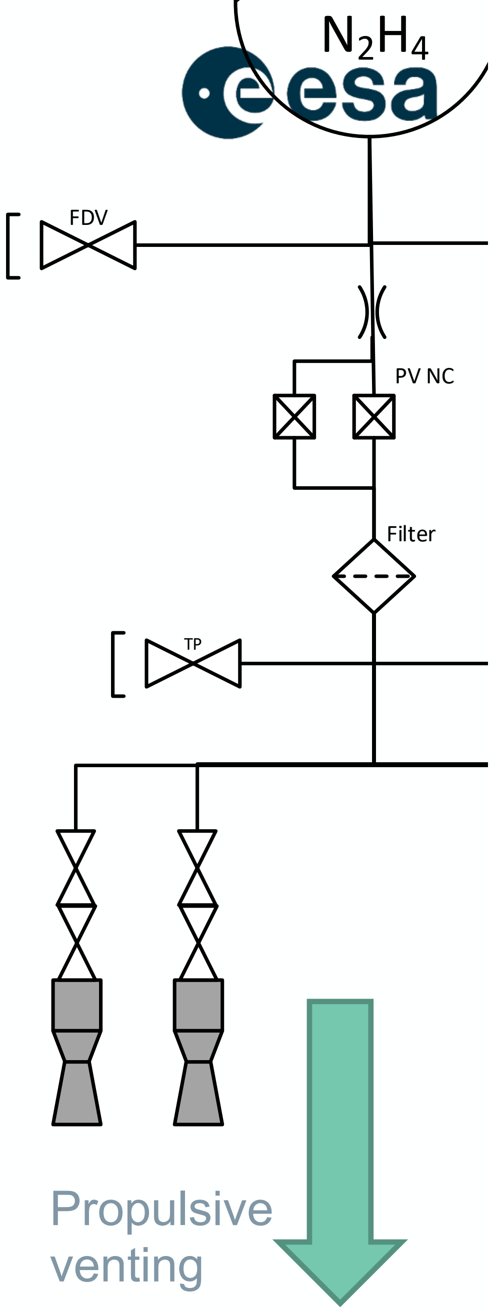
➢In addition to conservative estimates of **residuals**, which are unusable propellant mass, **gauging uncertainties** and **Δv margins** typically lead to significantly more propellant being carried than is actually required for the nominal mission.

Venting of Propellants

Venting of propellants is if possible performed propulsive. The thrusters are operated until no further propellant remains.

During this operation in order to be able to further telecommand the spacecraft, any uncontrolled tumbling or spinning has to be avoided.

After venting of propellants through thrusters, pressuring gas may remain in tanks (due to diaphragm tanks, impossibility of propulsive venting or previous isolation of high pressure section)



Venting of Pressuring Gas

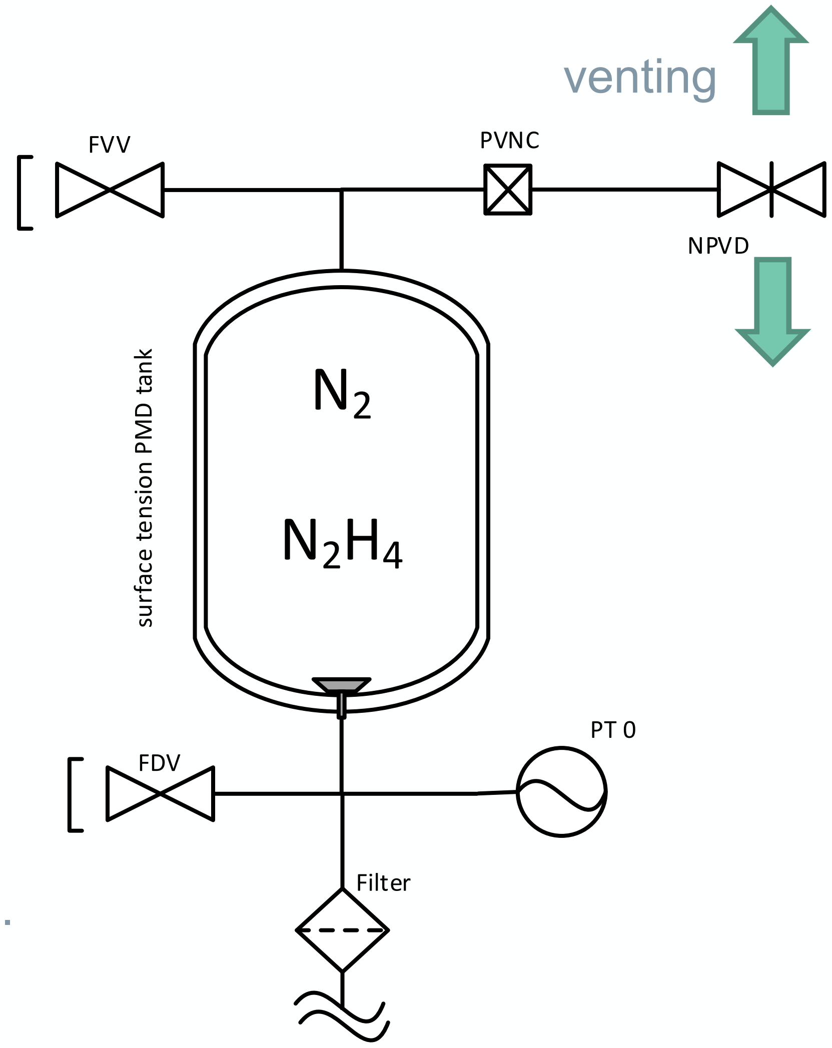
The remaining pressure on the gas side is often nominally low at end of mission (in fact it can be so low, that thermal expansion would lead to a theoretical burst of the tank only at temperatures beyond the tank's melting temperature).

In cases of uncertain remaining pressure levels, venting of gases is performed.

Venting of the gas side can be achieved by installing a non propulsive venting device (NPVD) and a normally closed pyrovalve.

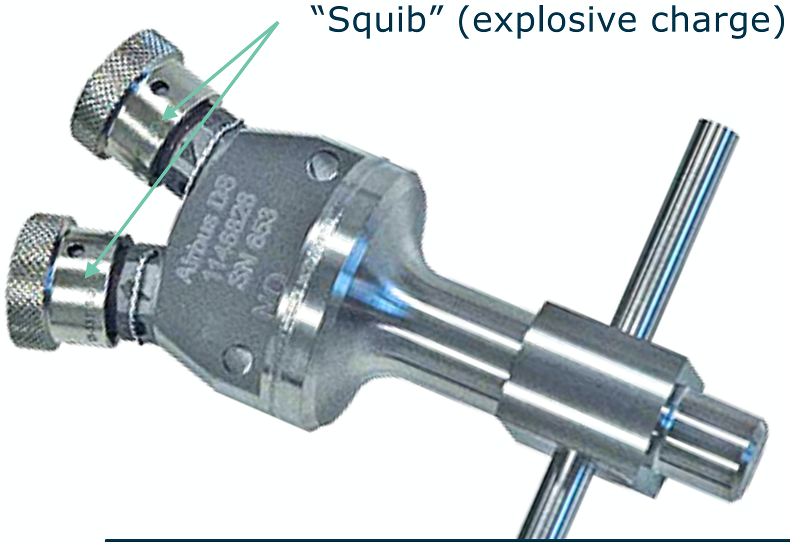
The NPVD ejects the gases equally in several directions in order not to create any momentum on the spacecraft.

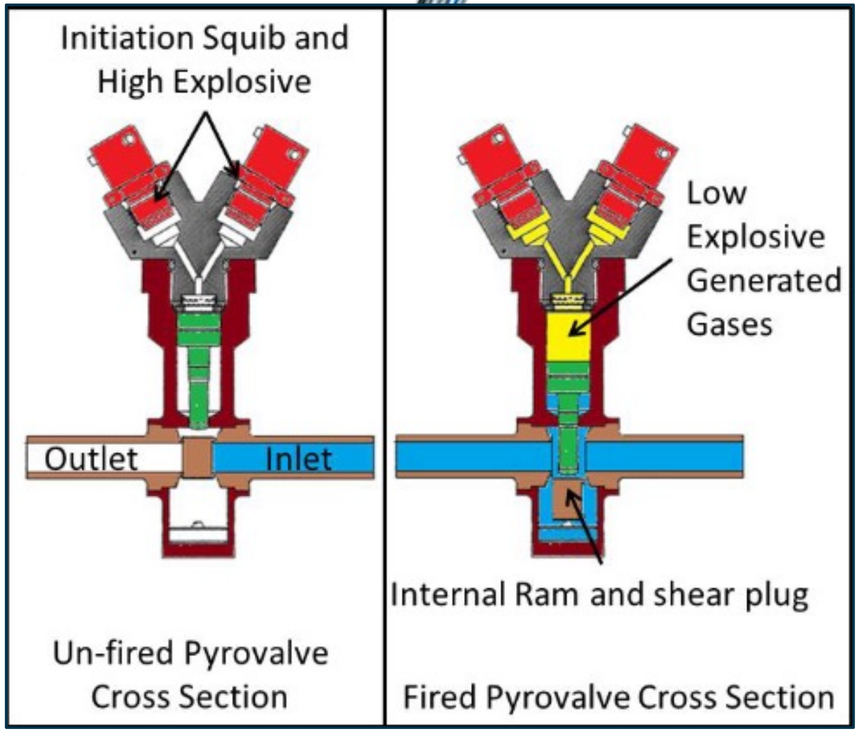
The pyrovalve ensures that there is no leak path, while it is normally closed. It is fired at the end of mission, after expulsion of propellants is completed.



Pyro Valve (PV)

- ➢Used for one shot isolation or opening of branches, sometimes to isolate for ground testing
- ➢Different to latch valve completely sealed (virtually no internal leakage)
- ➢Two types: Normally Open (NO) and Normally Closed (NC)
- ➢If fired in space and mission critical, typically placed in pairs (parallel NC, serial NO)
- ➢In case of planned multiple uses PV can be stacked in a so called pyro valve ladder
- ➢Problem for missions with long launch delay: durability of pyrotechnic squibs → replacement





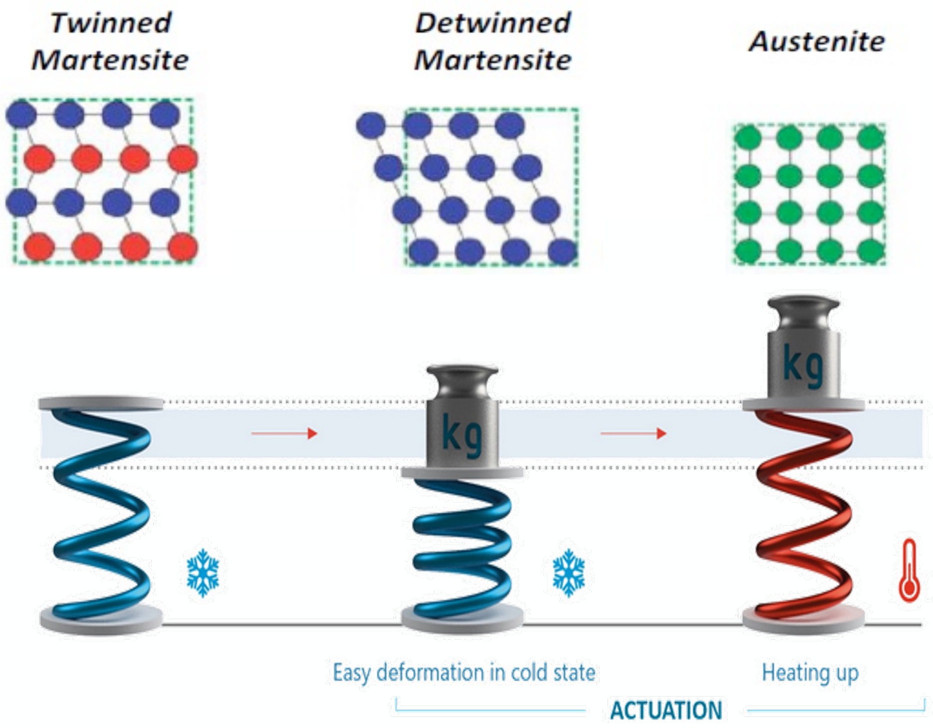
Image(s): http://www.space-propulsion.com/spacecraft-propulsion/valves/pyrotechnic-valve.html
James Richard, SLM Produced Hermetically Sealed Isolation Valve, 42nd Aerospace Mechanisms Symposium

SMA Valve

Pseudoelastic behaviour of shape memory alloys (SMA), such as nickel titanium: temperature induced phase transformation reverses previous mechanical deformation.

Advantages of using shape memory alloys to build a pyrovalve replacement:

- No life limited pyrotechnic charge.
- No pyrotechnic shock event.
- No handling & transport constraints, as with pyrotechnic hardware.
- Simple electrical activation reducing system cost (No pyro driver electronics needed).
- Insensitive to spurious signal induction and electrostatic discharge (activation time several minutes)



Image(s): https://www.kyodo-inc.co.jp/english/electronics/microfluidics/memetis.html

SMA Passivation Valve

SMA valve from ArianeGroup Lampoldshausen

Qualification for Pressurants (He, N2) and Propellants (MMH, NTO, N2H4)

Single shot valve for passivation

Mass: 0.18 kg incl. heater

Heater power: 2 x 12 W (primary and redundant)

Activation time: < 12 minutes

MEOP: 345 bar

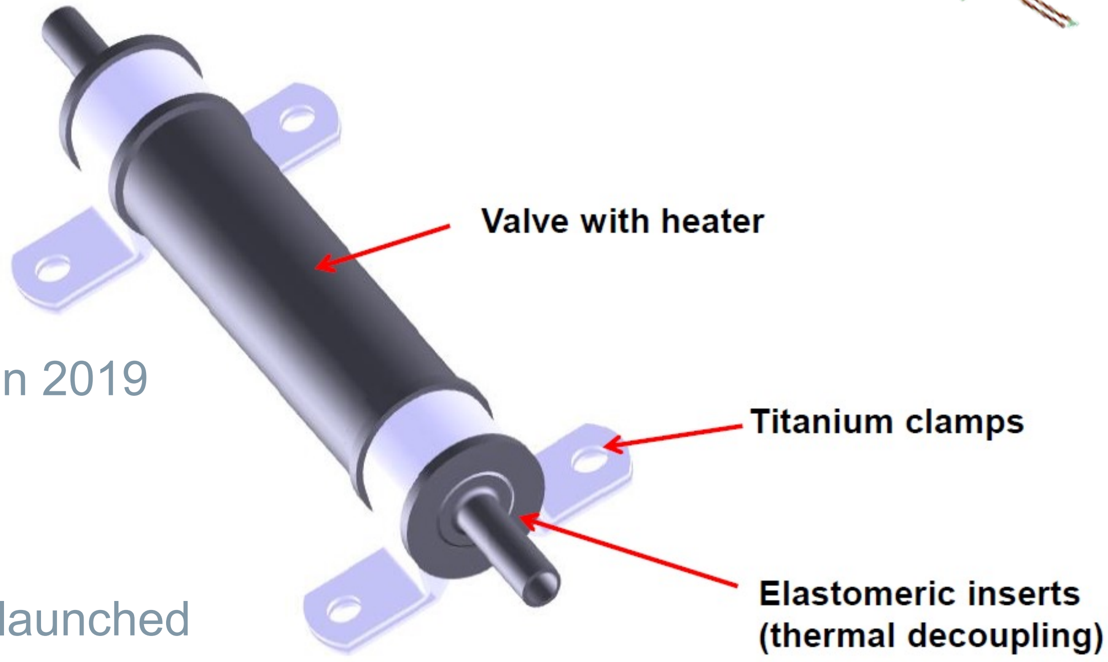
Interface: ¼” titanium tubing

Normally closed SMA valve qualified in the frame of ARTES in 2019

Δ Qualification performed with hydrazine

Total of 8 QM successfully tested under various conditions

Used for passivation on DLR’s Heinrich Hertz satellite (to be launched 2023, EOM: 2038)



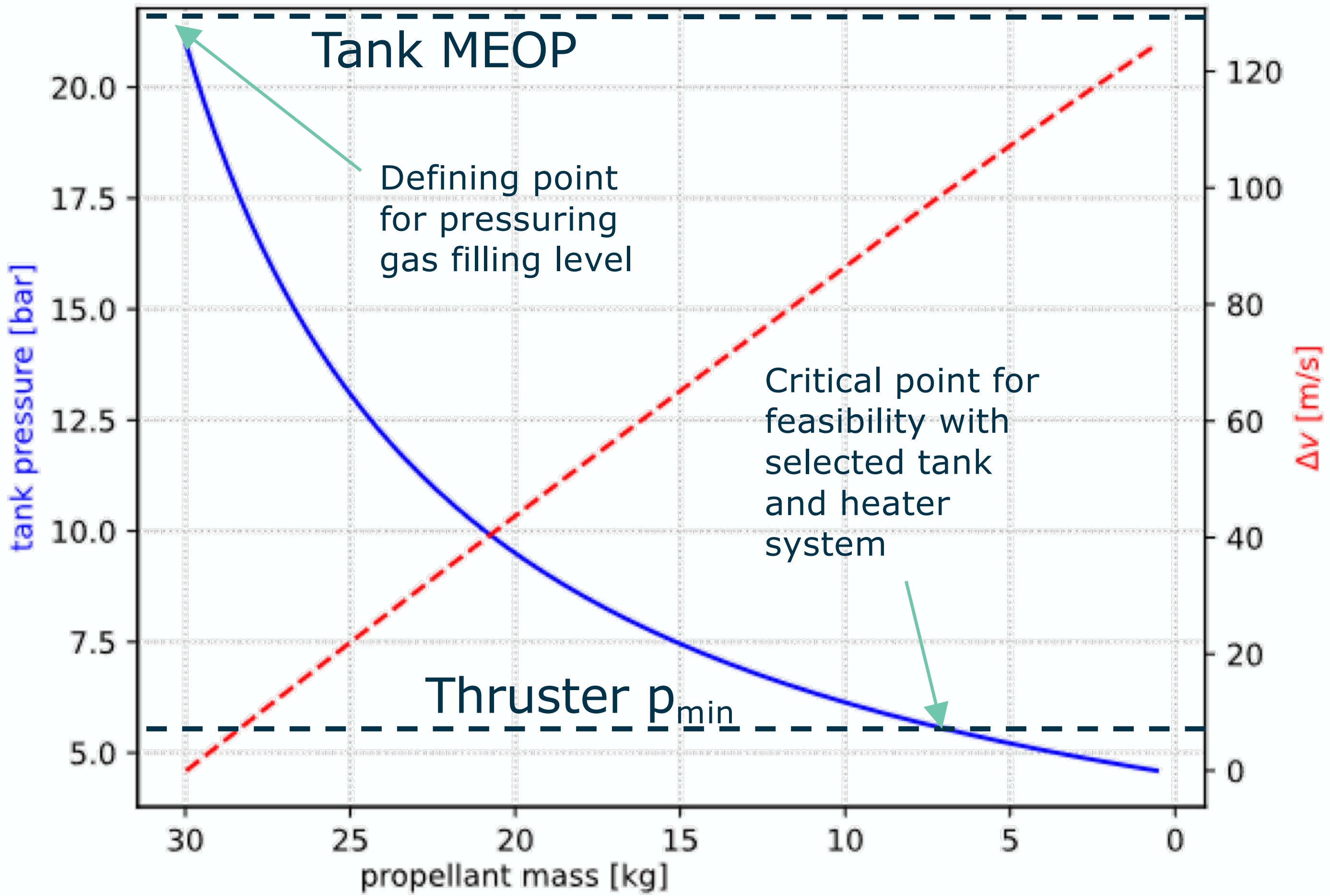
Image(s): https://www.space-propulsion.com/spacecraft-propulsion/valves/shape-memory-alloy-valve.html
http://epic-src.eu/wp-content/uploads/21_EPICWorkshop2017_ARIANEGROUP_2017-10-25-SMA-Presentation_EPIC.pdf

BACKUP

Performance Analysis (Blowdown)

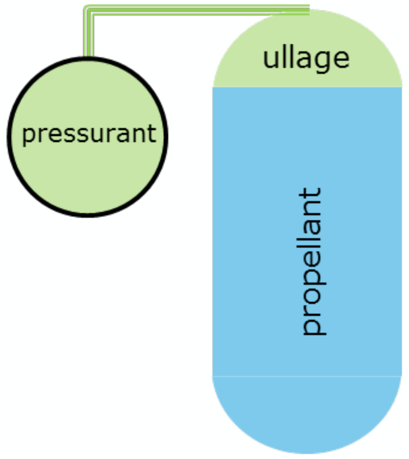
- Gas mass calculated such that initial pressure at maximum temperature is equal to equipment Maximum Expected Operational Pressure (MEOP), typically 24 bar
- Analysis is performed to verify that End of Life (EOL) pressure at minimum temperature is not below qualification limit of thruster, typically 5.5 bar
- Pressuring gases usually either nitrogen (N2) or helium (He) - trade off between cost and mass
- Ideal gas equation is accurate enough for this purpose

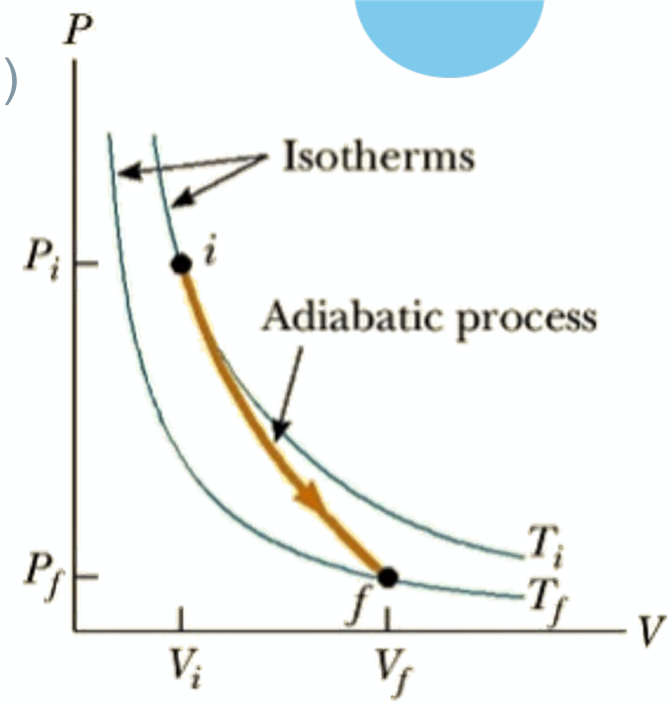
$$p\,V = \,m\,R\,T$$



Performance Analysis (Pressure Regulated)

- Typical dimensioning of pressuring gas tank:
  - 5% initial ullage volume in propellant tanks (needed to compensate for propellant thermal expansion)
  - 2% final residual in propellant tanks
  - Gaseous helium stored in pressure tank at an initial pressure of 310 bar
  - Final pressure in pressurant tank 40 bar (also accounting for any losses)
  - 22 bar tank pressure maintained for pressure fed engine
- Important consideration: isothermal vs. adiabatic expansion
  - Short burn duration – isothermal (compensated by heaters)
  - Long burn duration – adiabatic: may lead to pressure collapse (depending on Joule-Thomson coefficient of gas)





Microperforator

- Different configurations for different pressure levels
- Less than 95g
- Designed for a wide range of media
- Extended life time demonstrated in Qualification up to 28.5yrs
- Firing in hydrazine vapour and hydrazine liquid are planned as well
- Initial application is the passivation of the pressurant side, not the propellant side

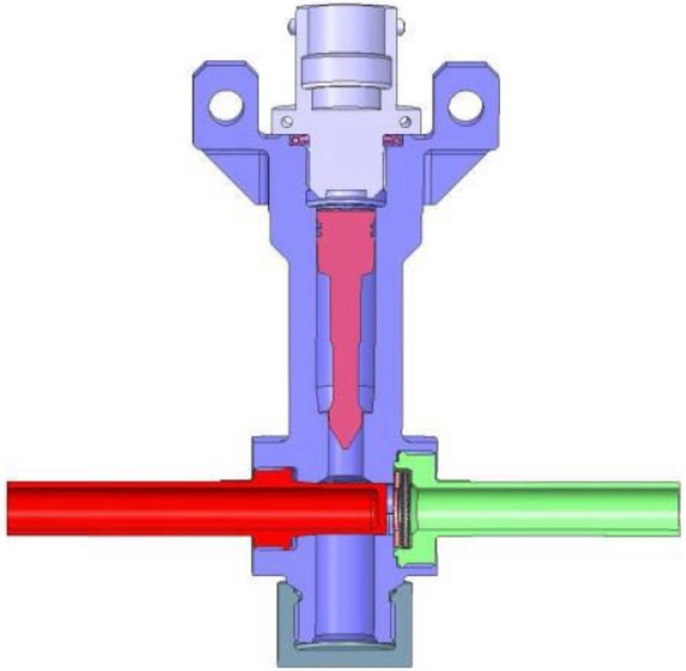


Figure 2: Cut view of the μperforator

μPERFORATOR, A SOLUTION FOR FLUIDIC PASSIVATION; Marine Petrantoni(1), Nicolas Bocquillon(1), Denis Dilhan(2); Space Propulsion 2018

Three Barrier Requirement

- Isolation valves shall have a leakage rate below 1e-6scc/s Helium

- Pyrovalves shall have a physical barrier (to be ruptured for activation) between inlet and outlet of the valve

- Three barrier rule to be applied to any leakage case, which could harm personnel. Pyrovalves are considered as two barriers (physical barrier) but need special drivers to make them safe on ground.

- Reliability shall be foreseen up to around 15 to 20 years in orbit without maintenance.