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Space Suit Portable Life Support System (PLSS)
Oxygen Regulator History, Development, & Testing Results

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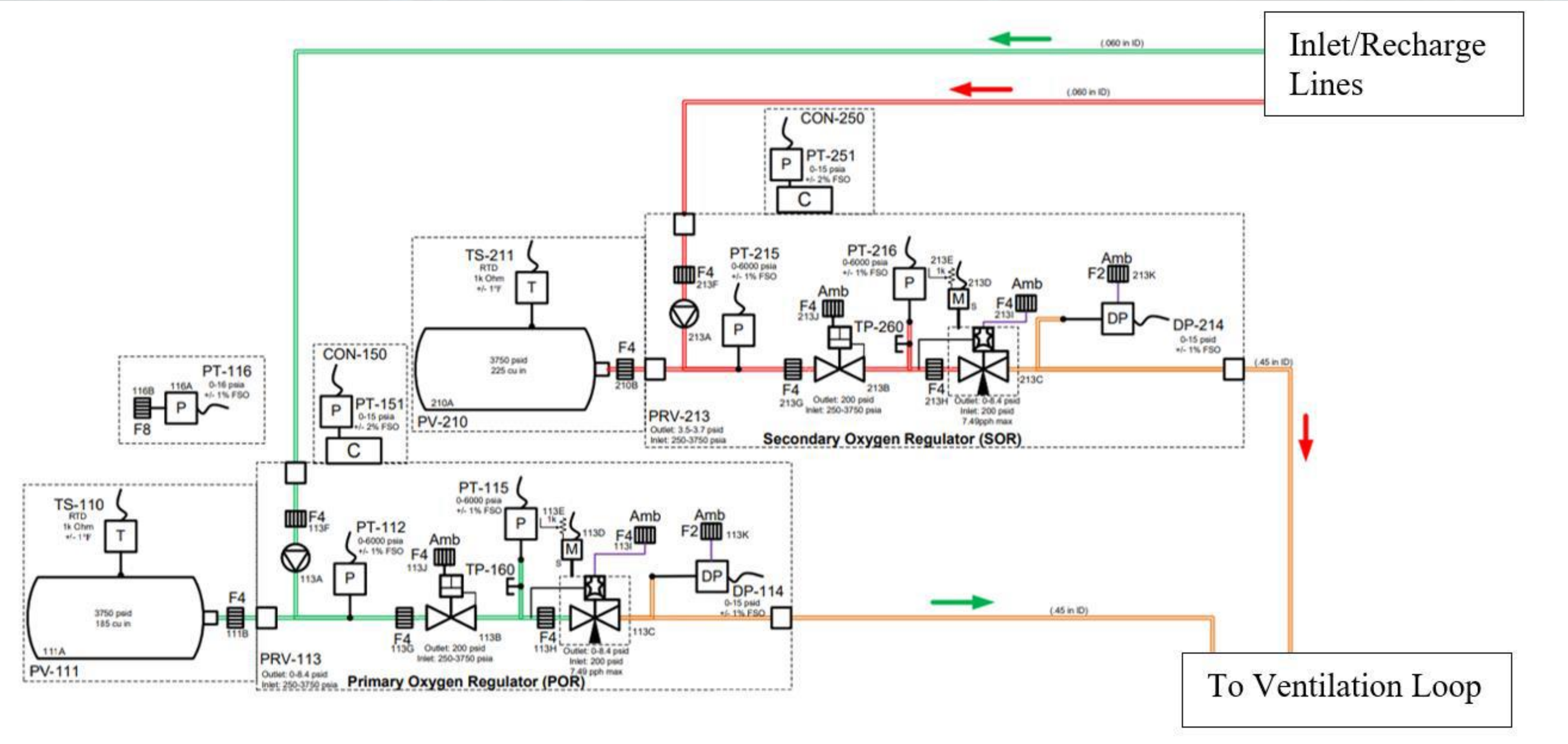
Introduction

- Portable Life Support System (PLSS) consists of two oxygen regulators
  - Primary Oxygen Regulator (POR) – provides variable pressure setpoints for Extra-Vehicular activity (EVA), prebreathe, leak checks, airlock ops, & DCS treatment
  - Secondary Oxygen Regulator (SOR) – Backup regulator to provide pressurization support, CO_2 washout/removal, trace contaminant removal, & limited convective cooling
- Regulator Design Safety
  - Space suits operate at 100% O_2 which is extremely reactive
  - Laboratory failure of the EMU regulator in 1980 drove regulator changes
  - Regulator is a two-stage design to prevent over pressurization in case of stage failure
- Prebreathe and Decompression Sickness (DCS) Treatment
  - Regulator has variable setpoints allowing more prebreathe protocol options which can allow quicker start to the EVA while still avoiding DCS risk scenario
  - Regulator can set a higher pressure to treat cases of DCS immediately

Regulator History

- Apollo
  - Primary Oxygen Regulator (POR) & Oxygen Purge System (OPS)
    - POR operated at ~3.85 psid with a tank at ~1400 psia
    - OPS was manually activated. It operated at ~3.7 psid Crew Cabin was at 5 psia 100% O_2 which meant no prebreathe was required, but has a high fire risk
- External Mobility Unit (EMU) Shuttle/ISS
  - Dual Mode (Primary) Regulator and Secondary Oxygen Pack (SOP)
    - Provides either EVA mode at ~4.3 psid or Intravehicular Activity (IVA) mode from a ~1100 psia tank
    - SOP is a two-stage regulator pressurized up to 7400 psia and regulates down to ~3.6 psid
- Orlan-M
  - 3 stage regulator with identical primary & secondary two-stage pressure reducing valves each on their own tank at ~6200 psia
    - Duplicate 3^{rd} stage regulators operates off the primary tank & reducing valve
  - Backup setting sources pressure from the primary tank into and injector and out a dump valve
    - Emergency supply setting sources from the secondary tank and goes into the injector and a secondary port in the helmet and out a dump valve

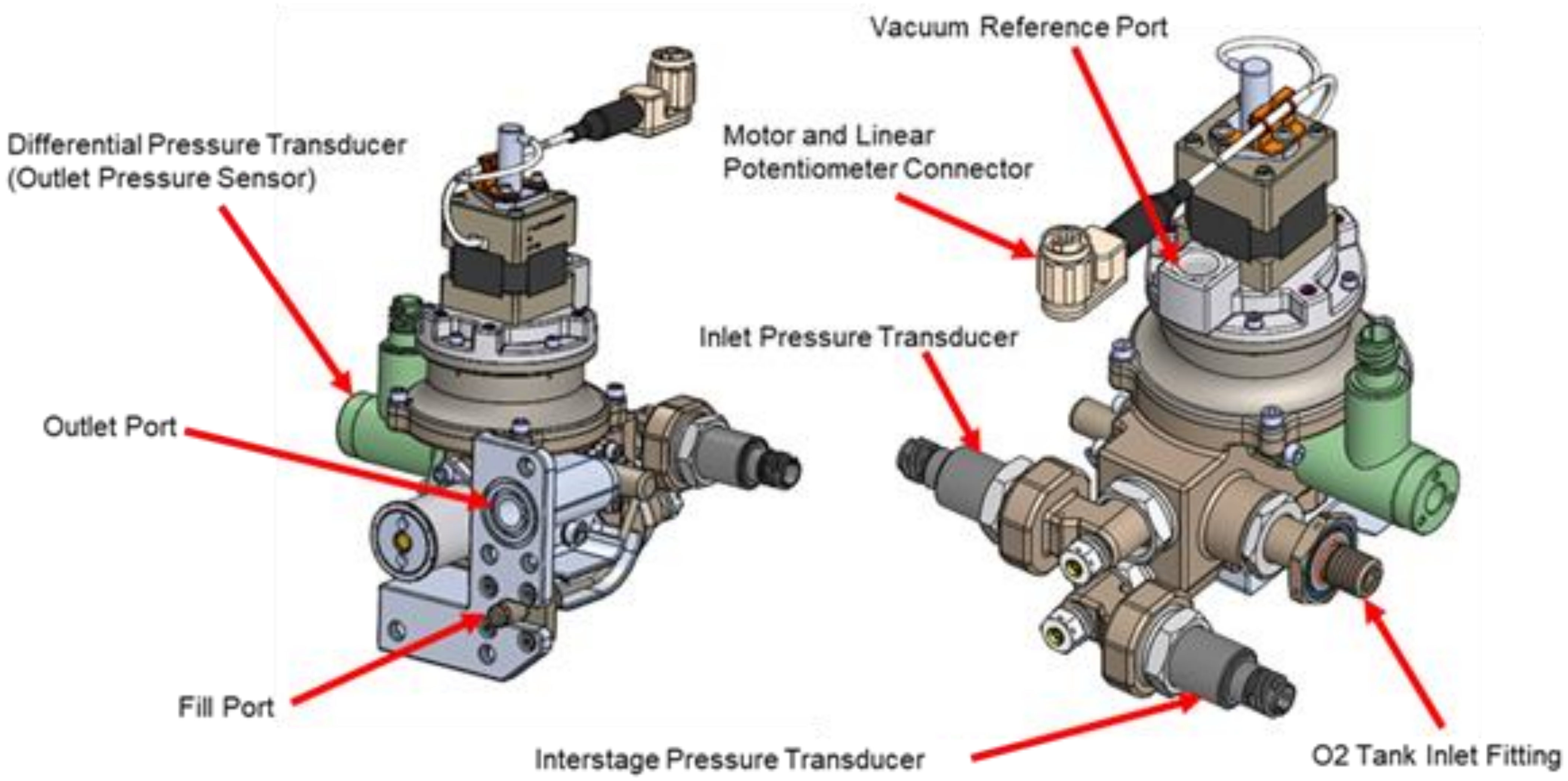
PLSS Oxygen Assemblies Pneumatic Diagram



Advanced Regulator Design

- Maximum Expected Operation Pressure (MEOP): 3750 psia
  – Nominal 3000 psia based of charging systems planned & available on orbit
- Flowrate: 5.6-7.49 pph maximum
- Fill Port & Check Valve
- Pressure monitoring sensors
- Two Stage Design – Inlet 250 – 3750 psia, interstage 200 +/- 40psia, outlet 0-8.2psid
  – First Stage Failure Tolerant – Second stage will regulate pressure up to 3750 in case of first stage failure
  – Second Stage Failure Tolerant – RV is designed to keep suit pressure < 10.1psid up to 7.49pph
- Linear Actuator & Potentiometer – Pressure control from 0-8.2psid
  – Stroke limiter stops regulator before exceeding RV crack pressure (8.6 psid)
  – On/Off shutoff feature – Setting the second stage to 0 psid puts the regulator in shut-off

Regulator External Diagram



xEMU Controls & Setpoints

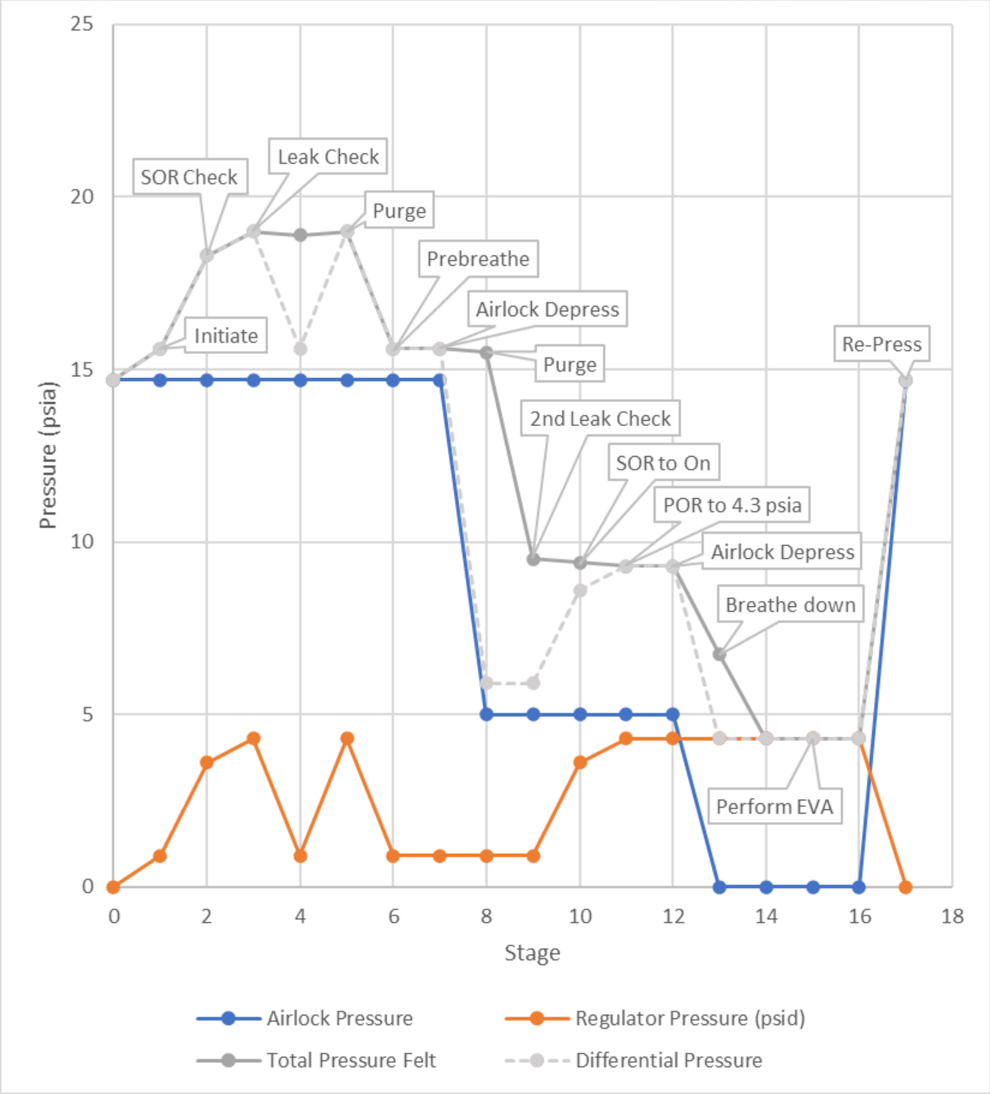
- Motor provides flexibility to provide any setpoint between 0-8.2 psid
  - 4.3 psid is nominal EVA pressure
  - 5.0 & 6.2 psid allow for a shorter prebreathe if needed
    - Crewmember can start egress and move to work location before pressure reduction to nominal 4.3 psid
  - 3.6 is backup SOR pressure set at the beginning
  - 8.2 psid is used for DCS treatment as needed
  - 0.9 is for purge and prebreathe airlock ops
  - Setpoints can be added and removed as needed
- ISS is maintained at 14.7 psia at 21% O_2 which requires a long prebreathe
  - Future missions could use a lower 8.2 psia at 34% O_2 which could allow for a shorter prebreathe

PRV Setpoints Table

Setpoint (psid)	Purpose
0.9	POR - Purge/prebreathe (IVA)
3.6	SOR – nested backup pressure (EVA)
4.3	POR - Nominal EVA pressure (EVA)
5.0	POR - Reduced prebreathe (EVA)
6.2	POR - Reduced prebreathe (EVA)
8.2	POR – Reduced prebreathe and DCS treatment (EVA/IVA)

Nominal EVA Profile

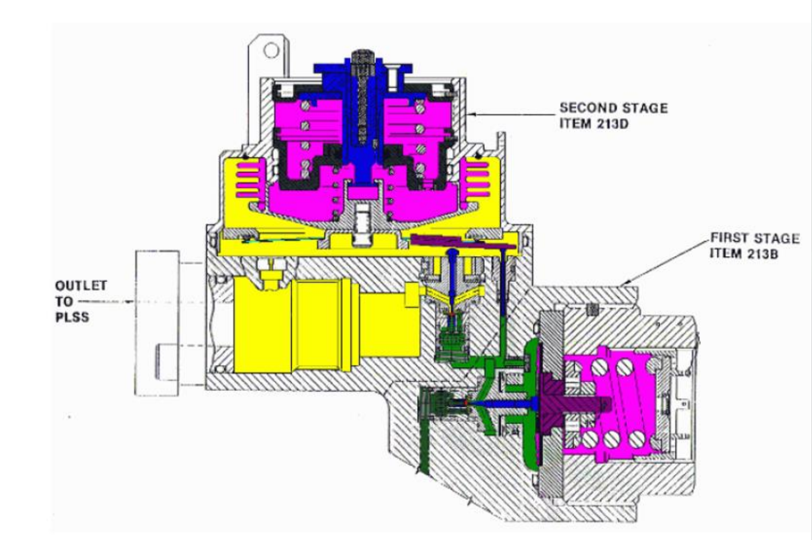
1. Initiate - Set POR to 0.9 psid
2. SOR check - set SOR to On
3. Leakage check
   – Difference between total felt pressure and differential pressure will cause a predictable pressure decrease as crewmember breathes down
4. Purge & Prebreathe
   – Purge for 10-12 minutes to achieve >95% O_2
5. Airlock Depress
6. Decay Pressure to 4.3 psia – Breathe down will slowly lower pressure
   – 5.0 or 6.2 setpoints on regulator can be used to control the pressure decay if needed to prevent DCS with reduced prebreathe protocols
7. Perform EVA
8. Repressurize Airlock



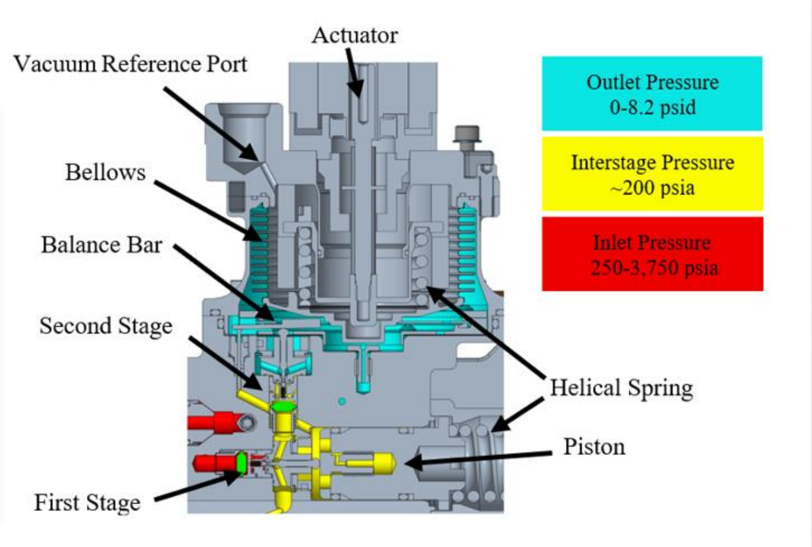
Nominal EVA Profile

Internal Operation

- Both stages use a ball and seat geometry to control flow and pressure
  - 1st stage uses a piston sensing area
  - 2nd stage used a bellows pressure sensing area
- Linear actuator sets the spring force applied to the second stage bellows sensing area
  - Balances between spring force and sensing cavity
- Balance bar maintains tight regulation bands over all inlet pressures
  - Soldered onto Bellville spring and rests on poppet and balance pin
  - Balance pin is subject to interstage pressures and acts on balance bar to keep tight regulation bands in case of 1st stage failure



EMU SOP Regulator

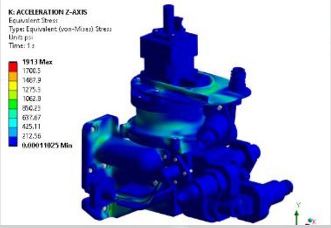


PRV 4.0 Regulator

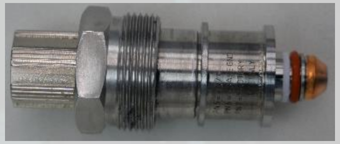
Detailed Design

- Oxygen Compatibility Analysis (OCA) & Testing
  - Analyzed then tested to ensure all ignition mechanisms due to pressurization, materials, & geometry are safe
- Finite Element Analysis (FEA)
  - All loads and conditions showed positive Margins of Safety (MOS)
- Sensor Selection
  - 6000 psia sensors are used
    - Interstage is sized for a 1st stage failure though nominal pressure 200 psia
  - Significantly higher than MEOP to allow proof pressure test processing
- Filters - 25-micron absolute and 10-micron nominal
  - 4 total: each regulator stage, check valve, and in between tank and regulator
  - Nickel 200 mesh switched to using a nickel sintered filter to meet requirements
- Temperature During Discharge/Purge
  - During a purge event gas temperatures can get as low as -42°F

OCA Cross Section

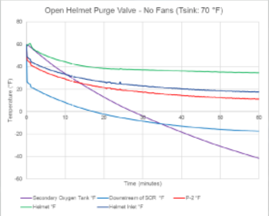


FEA Model



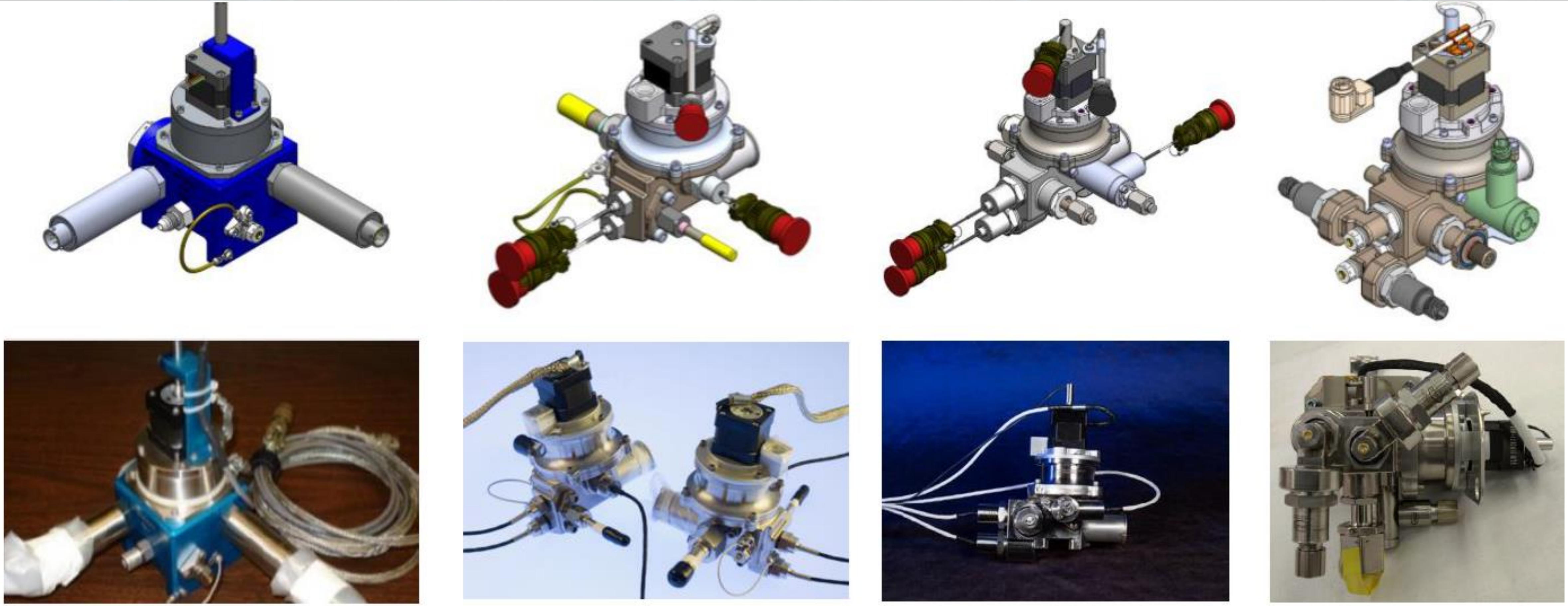
Pressure Sensor

Pleated (L) Sintered (R) Filter



Temperature Analysis

PRV Regulator Design Evolution

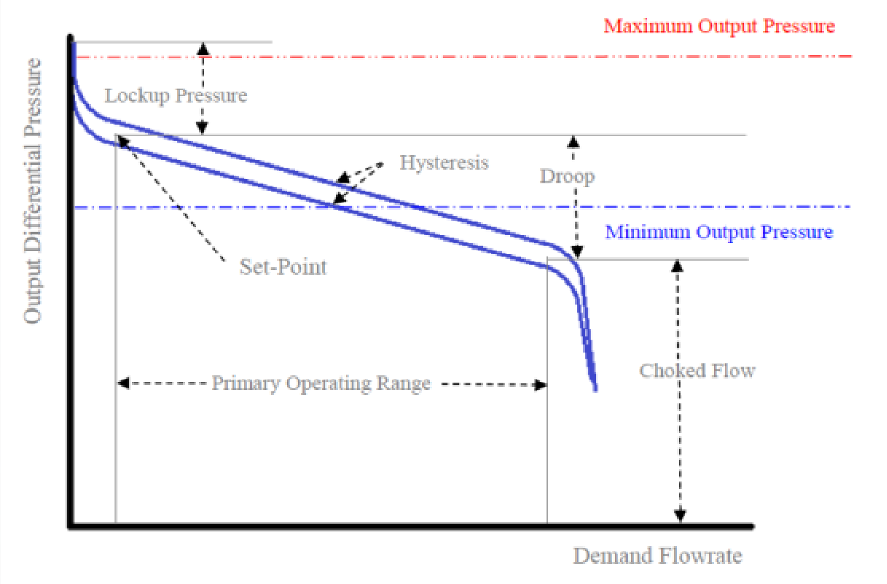


PVR 1.0 (PLSS 1.0)	POR 2.0 (PLSS 2.0)	POR 3.0 (PLSS 2.5)	POR 4.0 (xEMU DVT)

Primary Variable Regulator (PVR) 1.0 (2008 – 2009)

- Based on the SOP regulator design
  - Used same first stage and modified the second stage to introduce a linear actuator
  - Simplified aluminum body and nitrogen only were used as proof of concept
- Demonstrated the regulator could provide appropriate flowrates & setpoints from 0.4 psid to 8.2 psid
  - Maintained pressure tolerances for flowrates up to 5.6pph and inlet pressure up to 3750 psia
- Assembled and tested with PLSS 1.0
- Regulator output pressure vs flowrate demand typically follows the curve seen

Primary Variable Regulator (PVR) 1.0



Flowrate curve graph for regulator

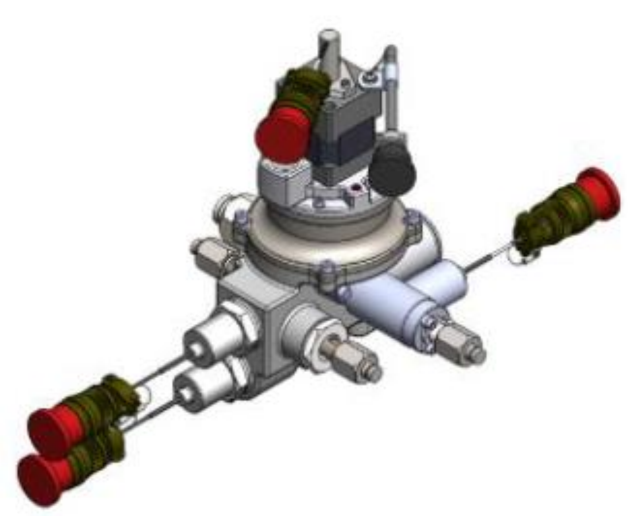
Primary Oxygen Regulator (POR) 2.0 (2011 -2012)

- Improved upon the PVR 1.0 design
  - Updated to Monel body for O_2 compatibility
  - Replaced diaphragm sensing mechanism in 1st stage with a piston sense mechanism
  - Optimized for mass reduction
- Testing & Analysis conducted
  - Oxygen Compatibility assessment conducted
  - Oxygen dry impact testing and 100mg/ft^2 dodecane conducted at White Sands Testing Facility (WSTF)
    - Evidence of combustion revealed without propagation
    - Cut O-ring and extruded back up ring found
  - Vibration & environmental tests run
    - Highest demand flowrates at 5.6pph not always met
    - Operated properly at 2.0 Grms, but at 3.3 Grms had some failed open second stage cases

Primary Oxygen Regulator (POR) – 2.0

POR 3.0 (2014-2015)

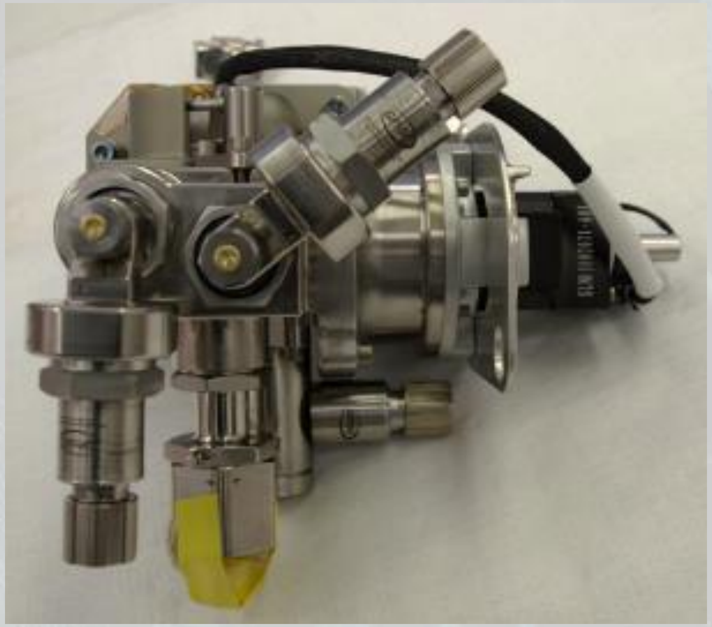
- Improved upon POR 2.0 findings
  - New transducers to meet updated requirements
  - New linear potentiometer design added
  - Interface fittings updated to be a primary metallic seal with 37° flared copper conical seals
    - Eliminates the need for a secondary elastomeric seal for future designs
- Testing conducted
  - Integrated with PLSS 2.5 prototype
  - Basic flow mapping conducted - most cases were able to meet the 5.6 pph flowrate, though not all:
    - lowest inlet pressures (250 psia) and highest set pressure (8.2 psid) did not meet the 5.6 pph flowrate
    - Lower set pressure (0.4 and 0.9 psid) did not meet the 5.6pph flowrate



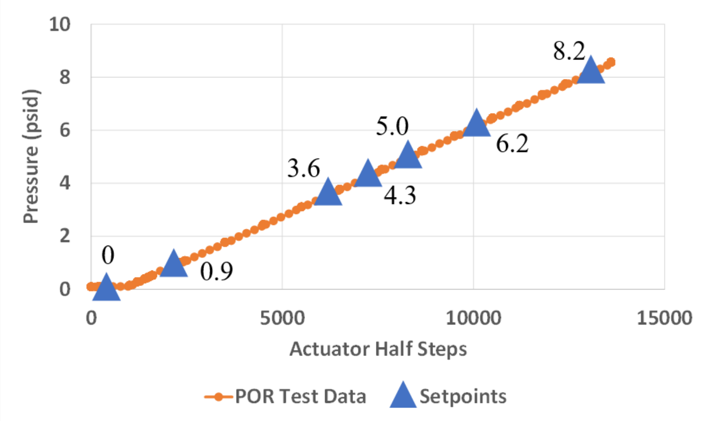
Primary Oxygen Regulator (POR) – 3.0

POR 4.0 (2019-2023)

- POR 3.0 was reworked to make the first version of the POR 4.0
- Introduced packaging and installation requirements for integration with the xEMU PLSS package
  - Outlet manifold added to place fill and outlet ports on the same plane
  - Monel Elbows added to move transducers for packaging
- Requirements and Testing Plan defined for flight
  - Thermal vacuum performance testing
  - Pre/post vibration testing
  - Oxygen Compatibility testing
- Basic flow mapping performed
  - Plotted graph on the right demonstrates pressure settings going both up and down and pressure using the actuator



Primary Oxygen Regulator (POR) – 4.0



Pressure vs Setpoints

xEMU Testing (2022 – 2023)

- POR & SOR 4.0 were first tested on the GN2 test rig at NASA
- The POR & SOR were then installed onto their respective tanks to make the Primary and Secondary Oxygen Assemblies (POA & SOA)
- POA & SOA were then installed on the PLSS and have gone through integrated testing with the xEMU as seen
  - The regulator operated as expected with only minor anomalies
  - Some issues with the actuator caused it to jam and skip steps, but using a different motor lubricant has appeared to resolve the problem

Primary/Secondary Oxygen Assembly (POA/SOA)

xEMU

Future Work

- xEMU POR 4.0 regulator design is still undergoing tests to refine the design and meet all flight requirements
  - Further flight qualification efforts will transition from the xEMU project to the EVA commercial partners now developing the suits
- Work remaining:
  1. Refinement of flow performance with new filter design
  2. Completion of sub-ambient performance and tuning of the regulator
  3. Design updates to fully address linear actuator jamming under all conditions with adequate force margins
  4. Component level launch vibration testing with both full charge and pad pressure to ensure no issues in lock-up

Conclusion

- This variable oxygen regulator has evolved through multiple iterations to refine the design and meet all flight requirements
  - Leverages the SOP design and adds new capabilities such as the motor settable second stage to remove mechanical linkages in current EMU SOP design
  - Enables exploration with varied pressure schedules, varied prebreathe protocols, & treatment of DCS
- Improved design & increased safety
  - Piston sensed first stage, better protection of soft goods, lower operating pressure from the SOP, integration of nickel mesh filters, stroke limiters
- Regulator has been tested for vibration, thermal, vacuum, oxygen, and oxygen challenge testing with contamination
- This regulator is expected to satisfy requirements for ISS missions, Artemis missions, and other future missions

QUESTIONS?

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