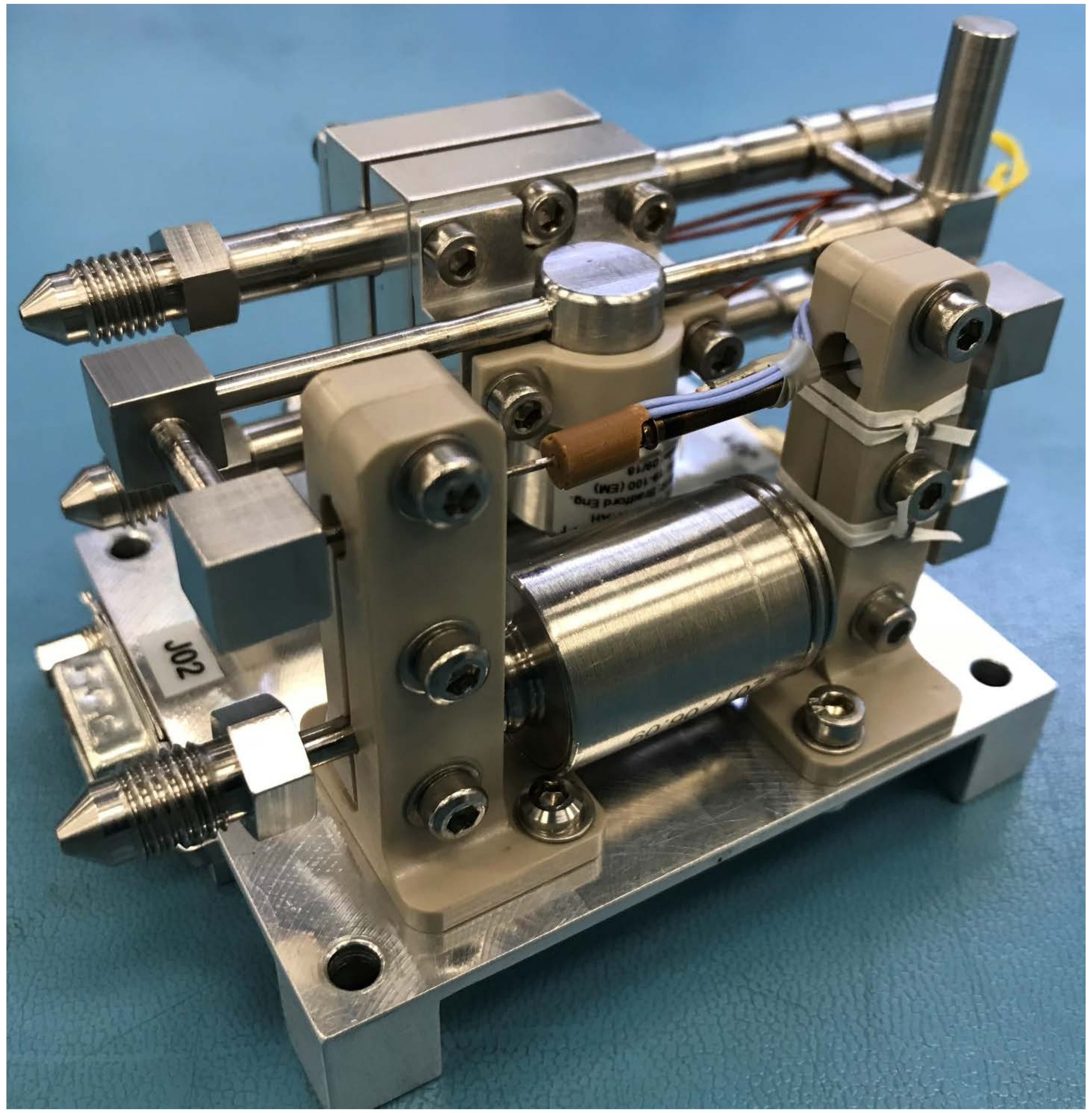
Consortium for Hall Effect Orbital Propulsion System Low Power

Initial High Pressure Krypton Functional Performance Results of the Fluid Management System

EPIC 2023, 9th of May 2023

GA 101004331

Starting point – 1 – System

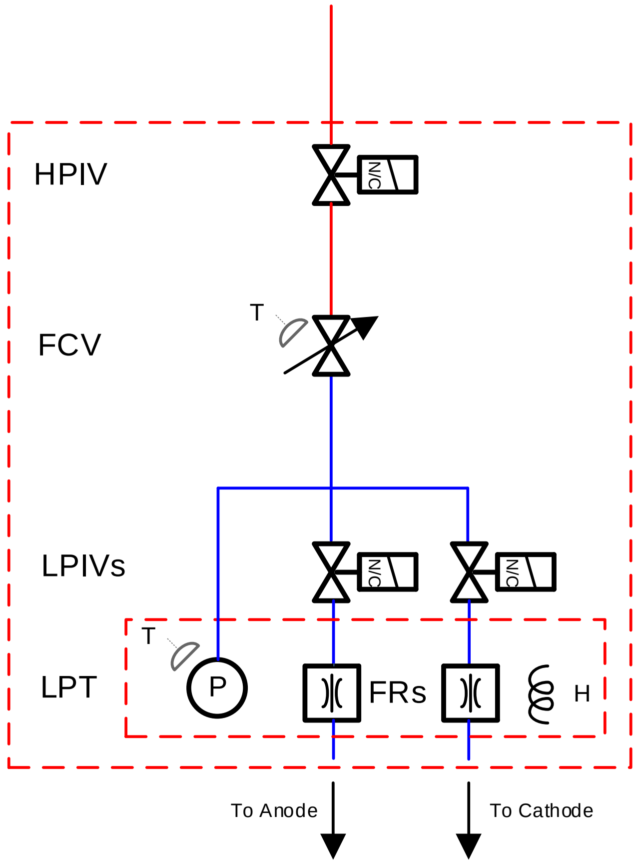


EM LEO FMS

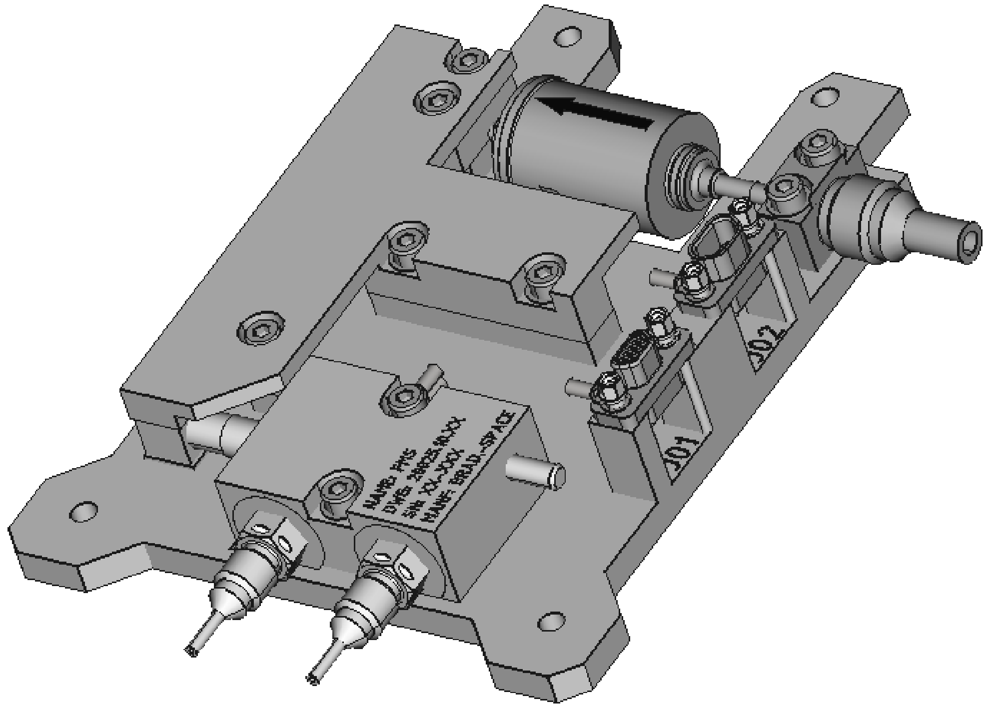
FCV : Flow Control Valve
FR : Flow Restrictor
H : Heater
HPIV : High Pressure Isolation Valve
LPIV : Low Pressure Isolation Valve
LPT : Low Pressure Transducer
T : Temperature Sensor

: High-Pressure Tubing (MEOP = 190 barA Xenon)

: Low-Pressure Tubing (MEOP = 10 barA Xenon)



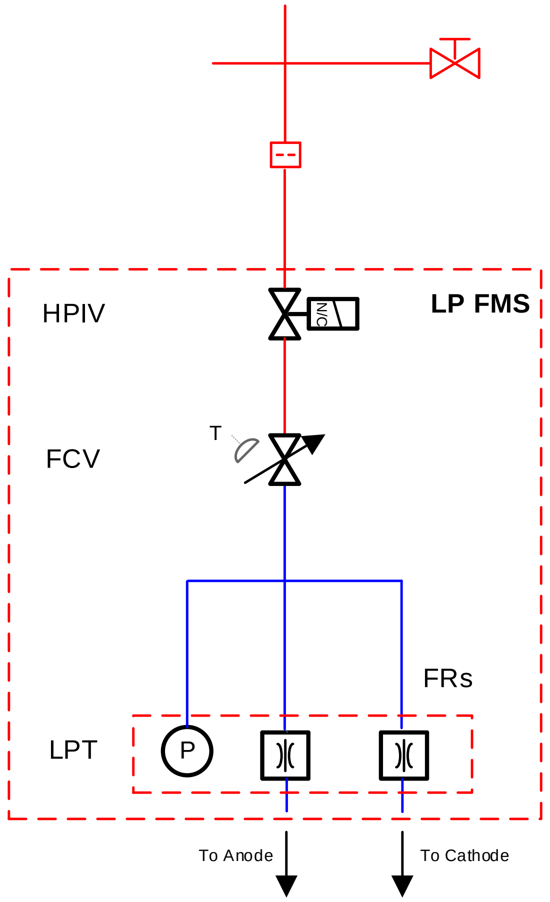
EQM LP FMS



FCV : Flow Control Valve
FR : Flow Restrictor
FVV : Fill & Vent Valve
HPF : High Pressure Filter
HPT : High Pressure Transducer
HPIV : High Pressure Isolation Valve
LPT : Low Pressure Transducer
T : Temperature Sensor

: High-Pressure Tubing (MEOP = 190 barA Xenon) (MEOP = 300 barA Krypton)

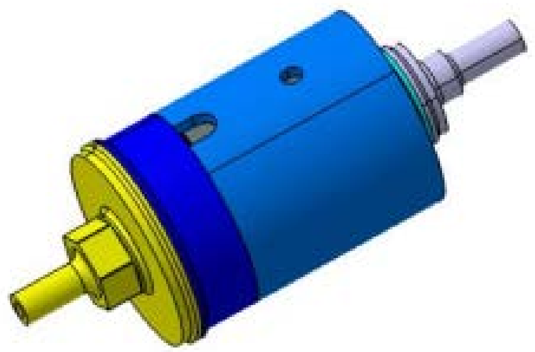
: Low-Pressure Tubing (MEOP = 10 barA Xenon) (MEOP = 10 barA Krypton)



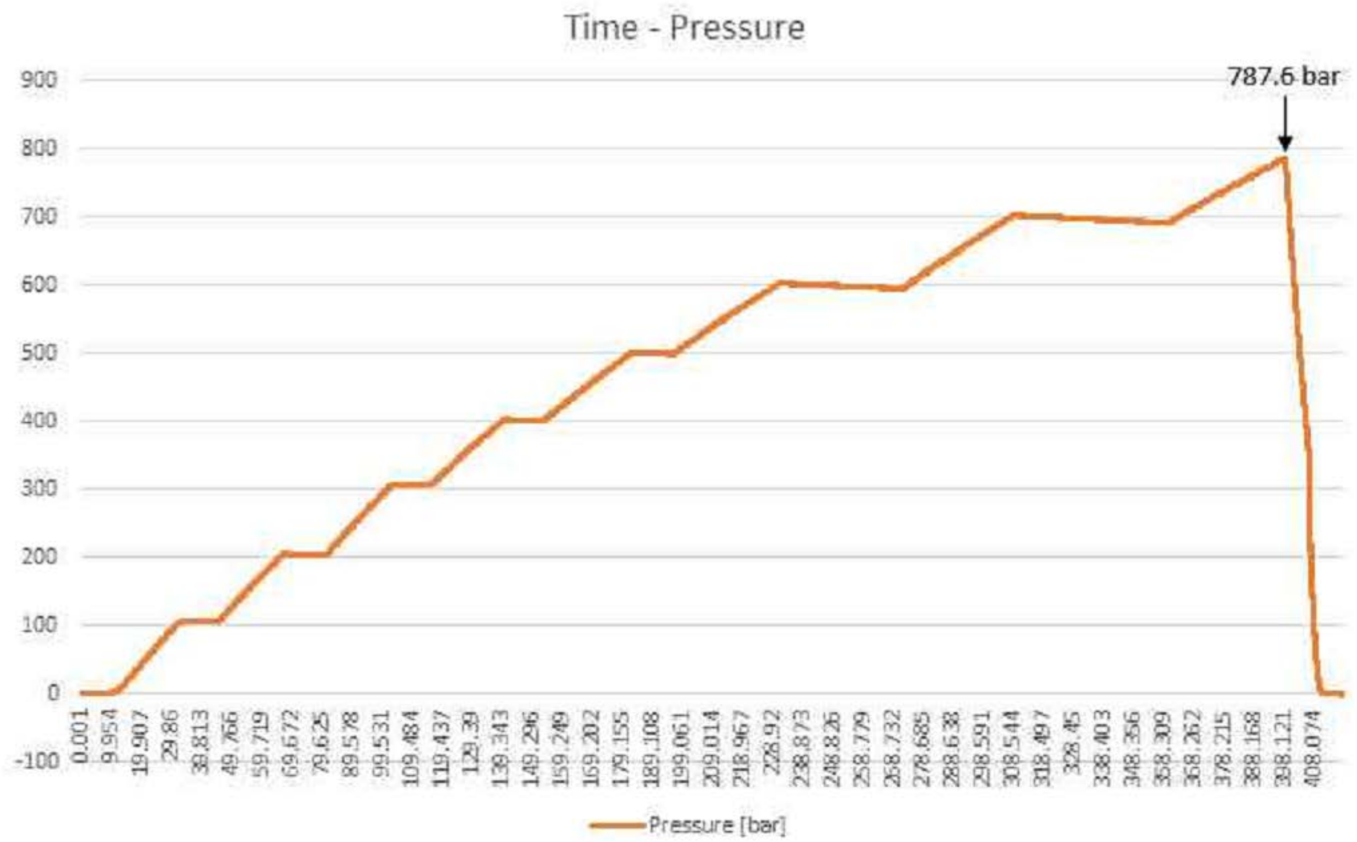
Starting point – 2 – HPIV

Previously HPIV design and QM build shown:

- Design review performed
- QM manufactured
- TRR performed



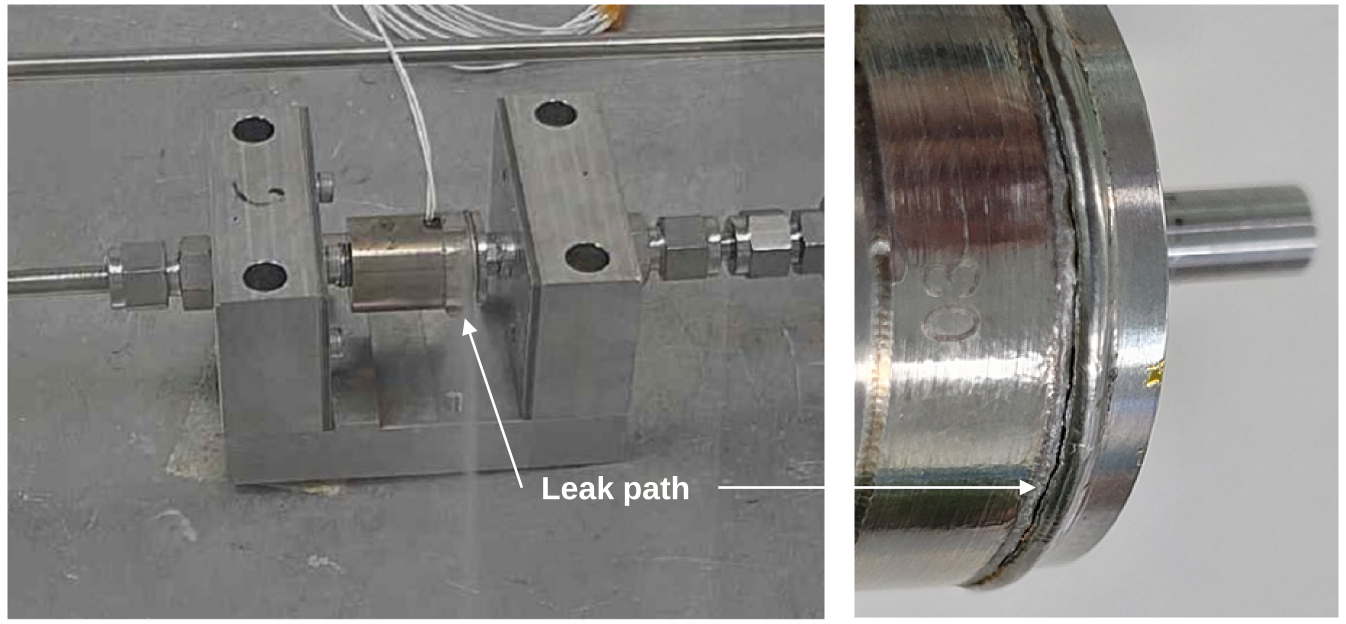
QM HPIV Design



QM HPIV Hardware

Qualification highlights:

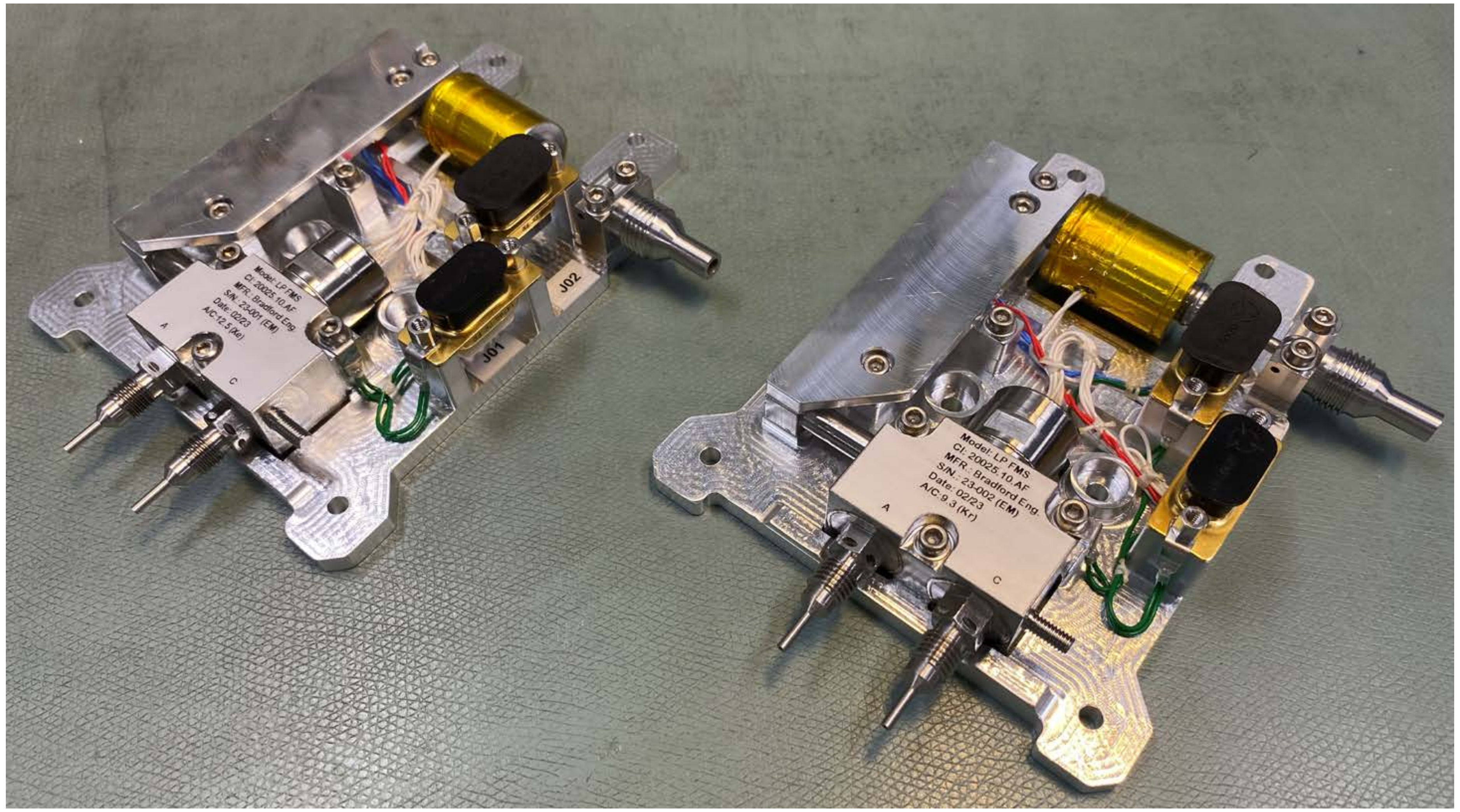
- Vibration test successful
- 50,000 cycles performed
- Burst pressure test (630 bar) successful
- Rupture test performed



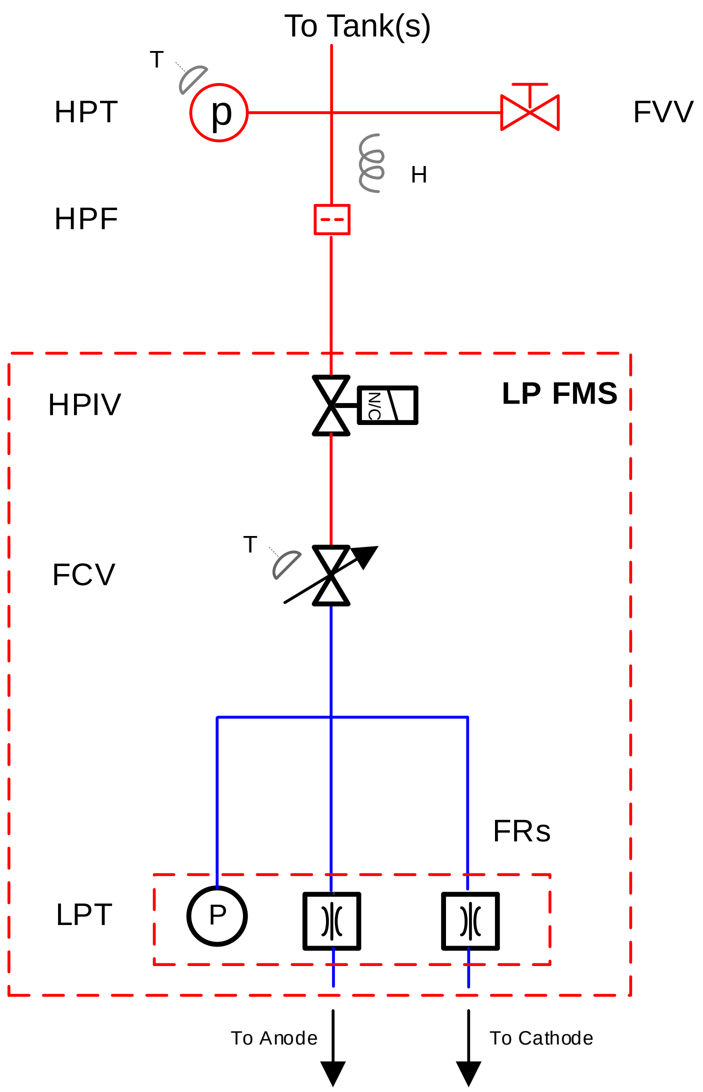
Rupture at 787.6 bar

General FMS design

- Single stage high pressure reduction and flow control. One FMS controls one electric thruster (HET, GIE or other).
- Fully weldable design with 300 barA MEOP.
- 2 serial high pressure barriers against internal leakage.
- 2 EMs produced in record time (one Kr and one Xe, each in 1.25 days), verifying the potential for serial production. Their only difference being the anode-to-cathode ratio.



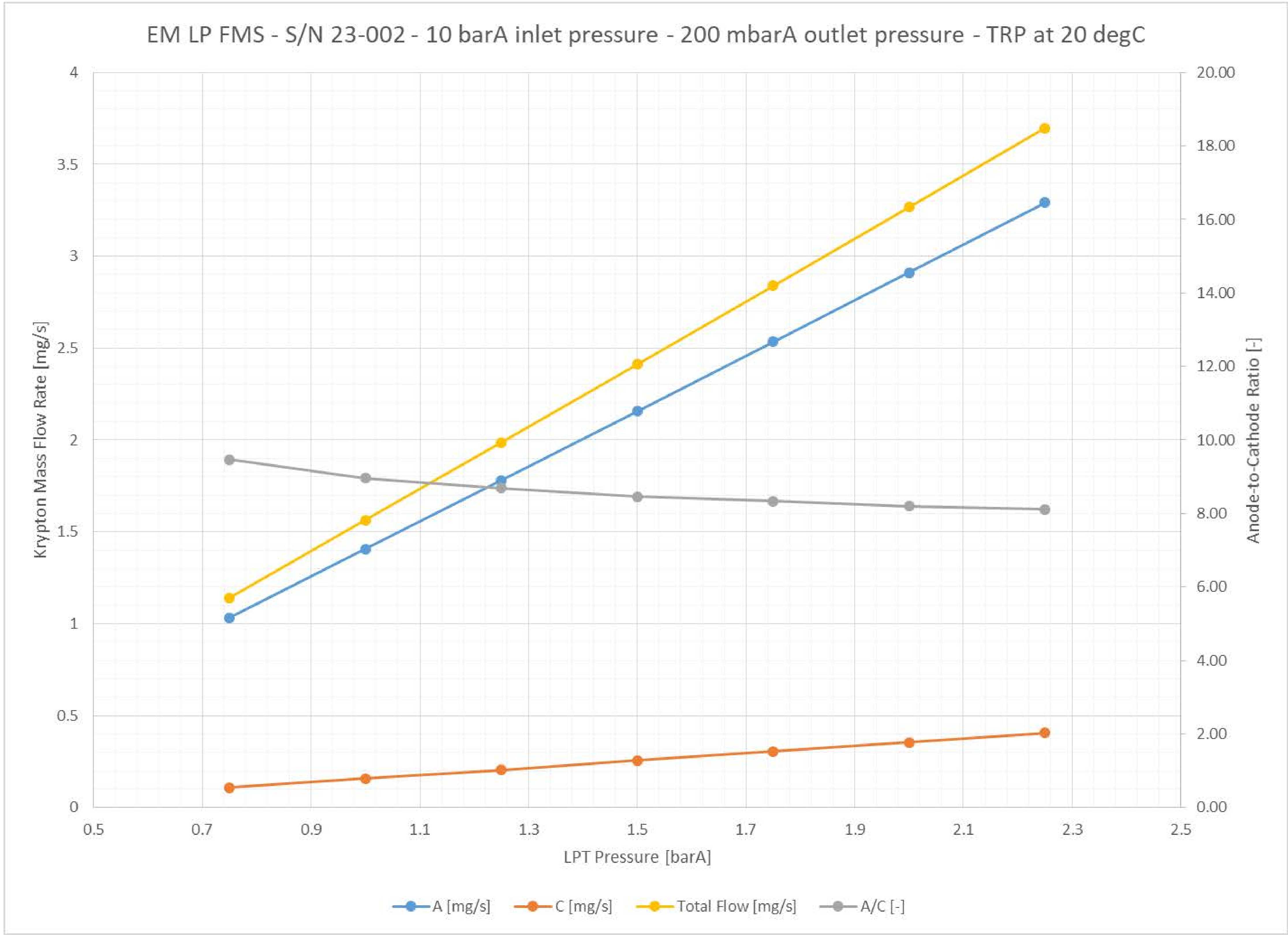
FCV	: Flow Control Valve
FR	: Flow Restrictor
FVV	: Fill & Vent Valve
HPF	: High Pressure Filter
HPT	: High Pressure Transducer
HPIV	: High Pressure Isolation Valve
LPT	: Low Pressure Transducer
T	: Temperature Sensor
(red line)	: High-Pressure Tubing (MEOP = 190 barA Xenon) (MEOP = 300 barA Krypton)
(blue line)	: Low-Pressure Tubing (MEOP = 10 barA Xenon) (MEOP = 10 barA Krypton)



Characteristic	EQM Low Power (LP) FMS
Medium	Xe, GHe, GN_2, Kr
Mass	<400 grams (with REACh compliance)
Size	105 x 127 x 20 mm
Internal Leakage	1E-5 scc/s GHe (at 10 barA and 300 barA for the 2 high pressure barriers)
External leakage	<1E-6 scc/s GHe
Maximum Expected Operating Pressure	300 barA (high pressure side)
Anode Flow Rate	Total flow rate: 0.9 - 4.5 mg/s Xe / 1.1 - 3.5 mg/s Kr
Cathode Flow Rate	Anode-to-Cathode ratio: as requested by customer
Electrical Interface	2x connectors: 1x power and 1x signal Nominal power consumption: ~2.5W Peak power consumption: ~14.1W
Operational Temperature Range	-20^{0}C to +75^{0}C
Unique Parts Count / Orbital Welds	40 / 3 → **Enables production rate target of 4 units per day**

Initial krypton test results – 1 – Performance overview

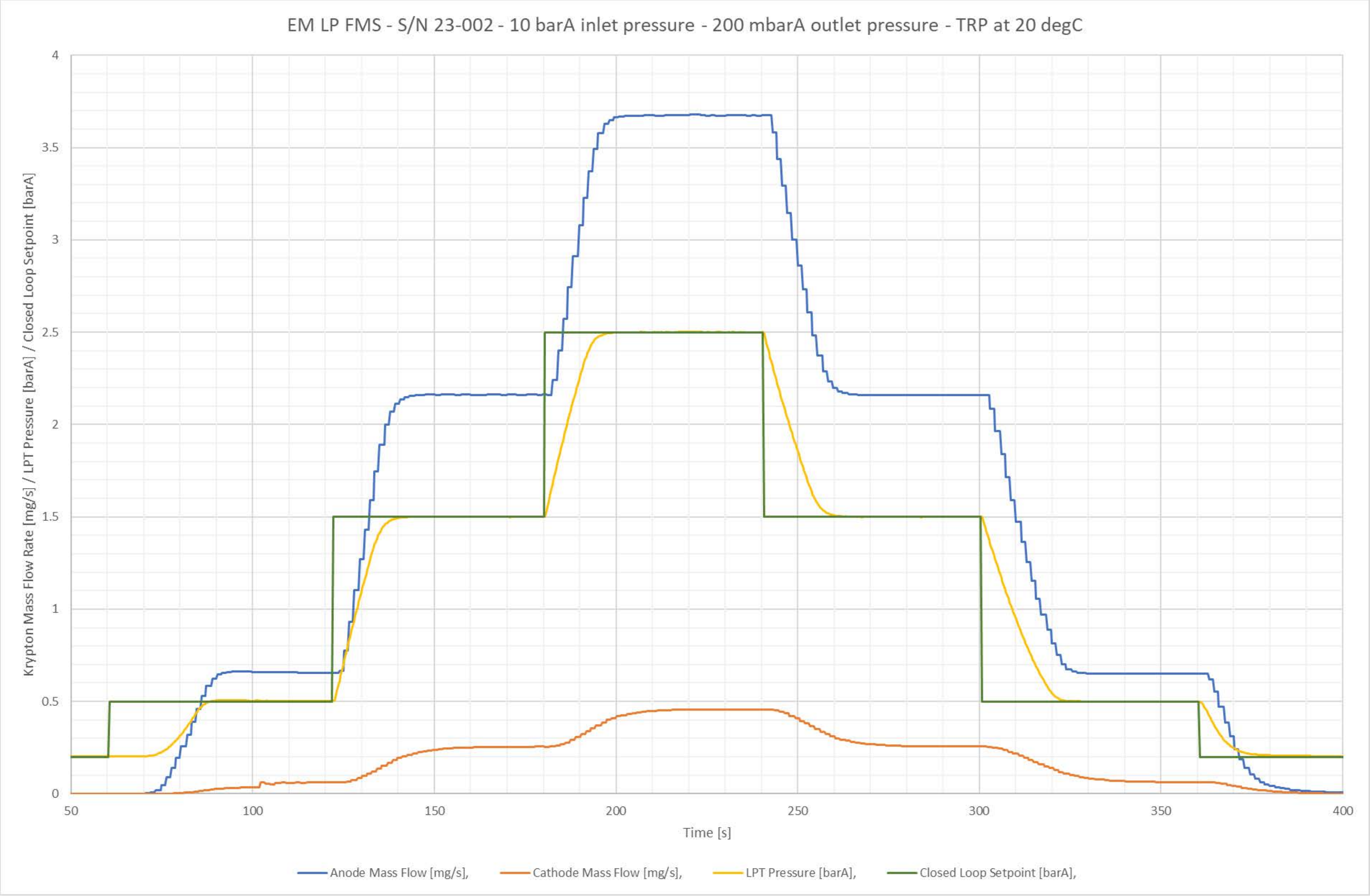
Krypton EM LP FMS inside TVAC chamber:

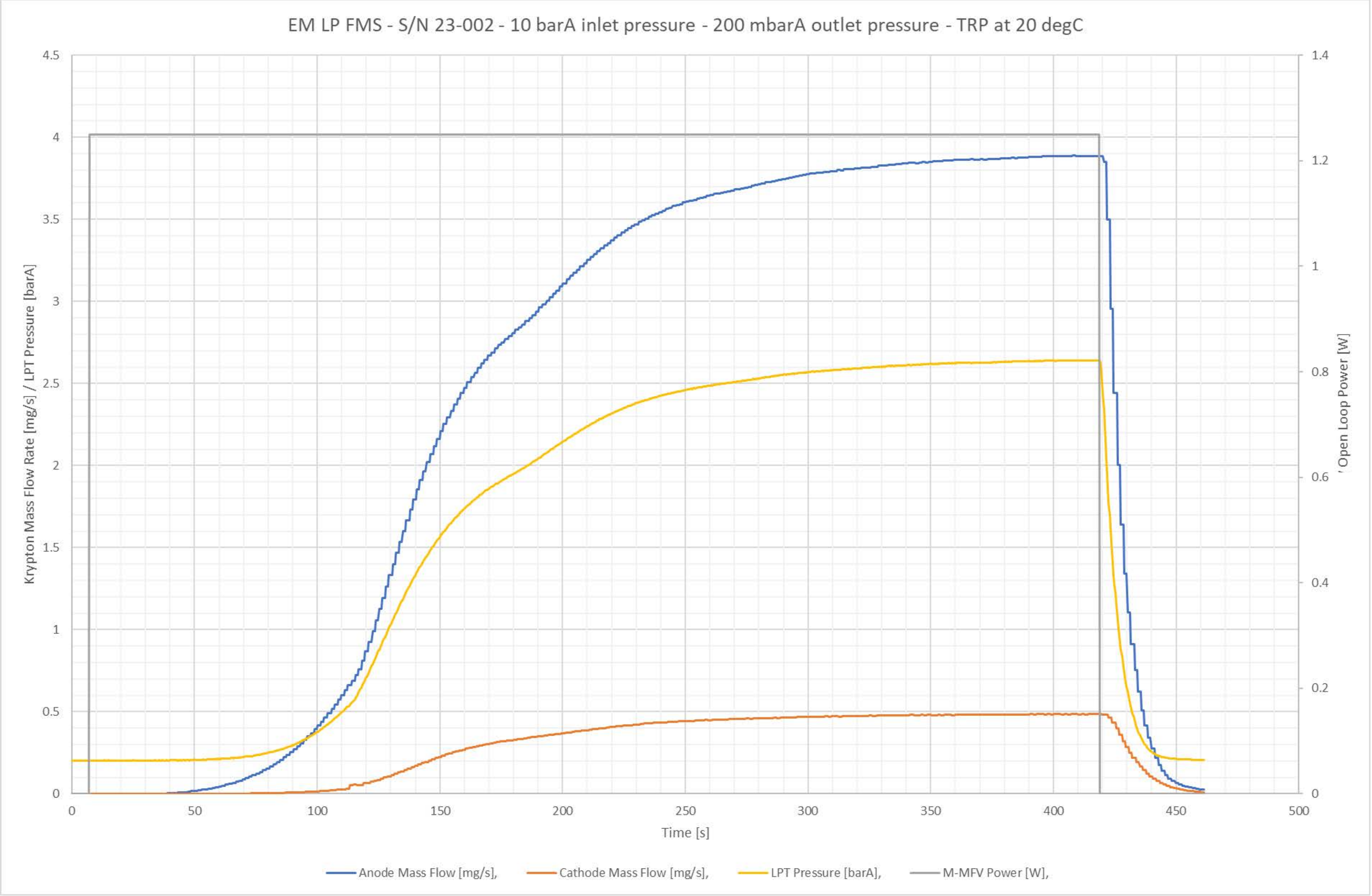


- The FCV is run in closed loop with a simple PID controller with the LPT by using the FMS EGSE.
- The FMS anode and cathode flow rates are directly measured at the outlet of the FMS by dedicated krypton flow sensors.
- The internal LPT pressure is recorded through the FMS EGSE.
- For Flight, the anode and cathode flow rates can be estimated by the LPT pressure and LPT temperature recording.

Initial krypton test results – 2 – 10 barA results

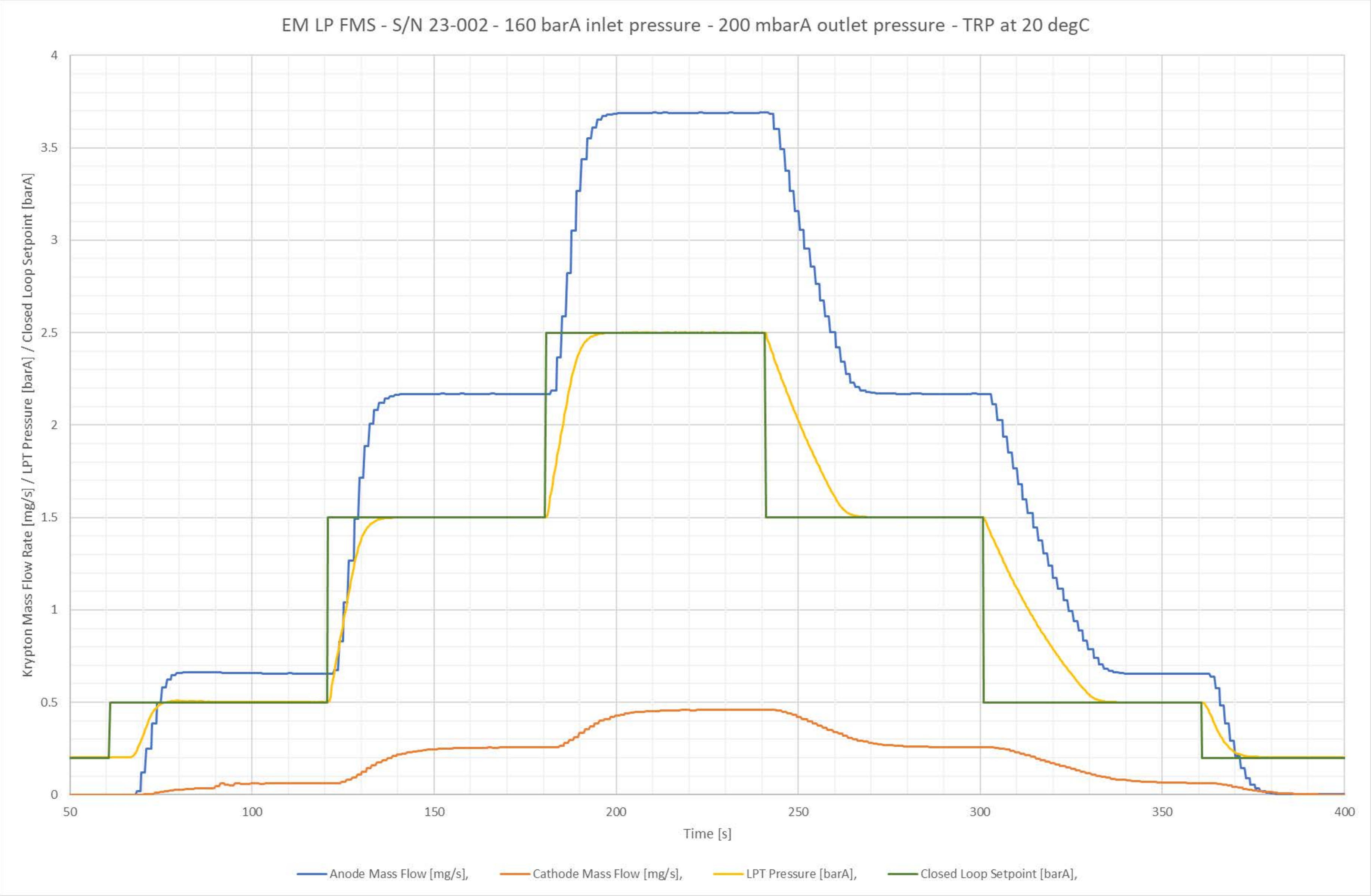
- Open loop (to ~2.5 barA LPT pressure) and closed loop (following a simple profile) test results achieved at 10 barA, 75 barA, 160 barA, 220 barA and 300 barA inlet pressure to the FMS, at 20°C TRP temperature and under vacuum conditions.
- No performance overshoots, undershoots or any other instabilities.
- Closed loop PID controller settings are the same as those used for xenon.

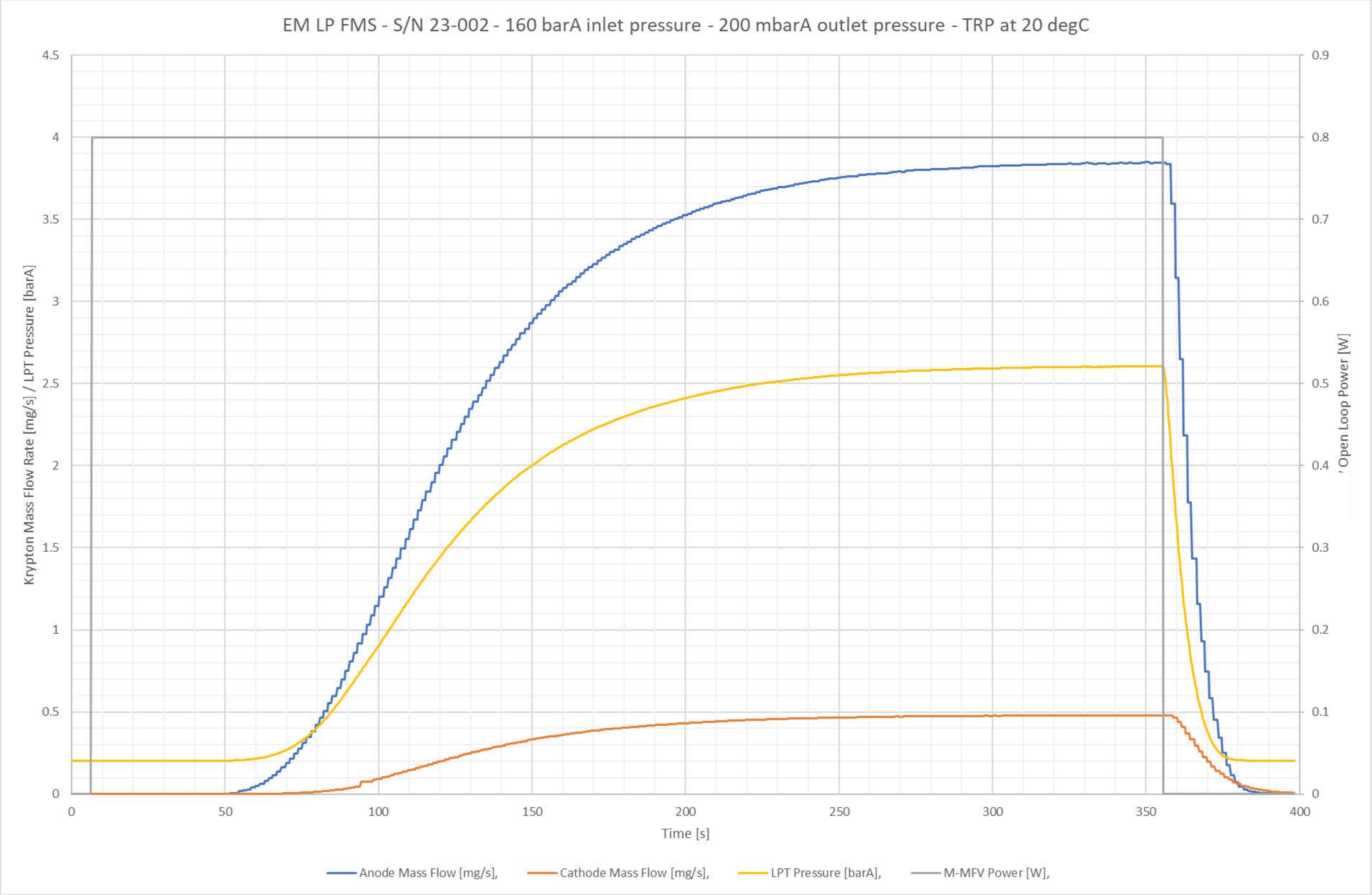




Initial krypton test results – 3 – 160 barA results

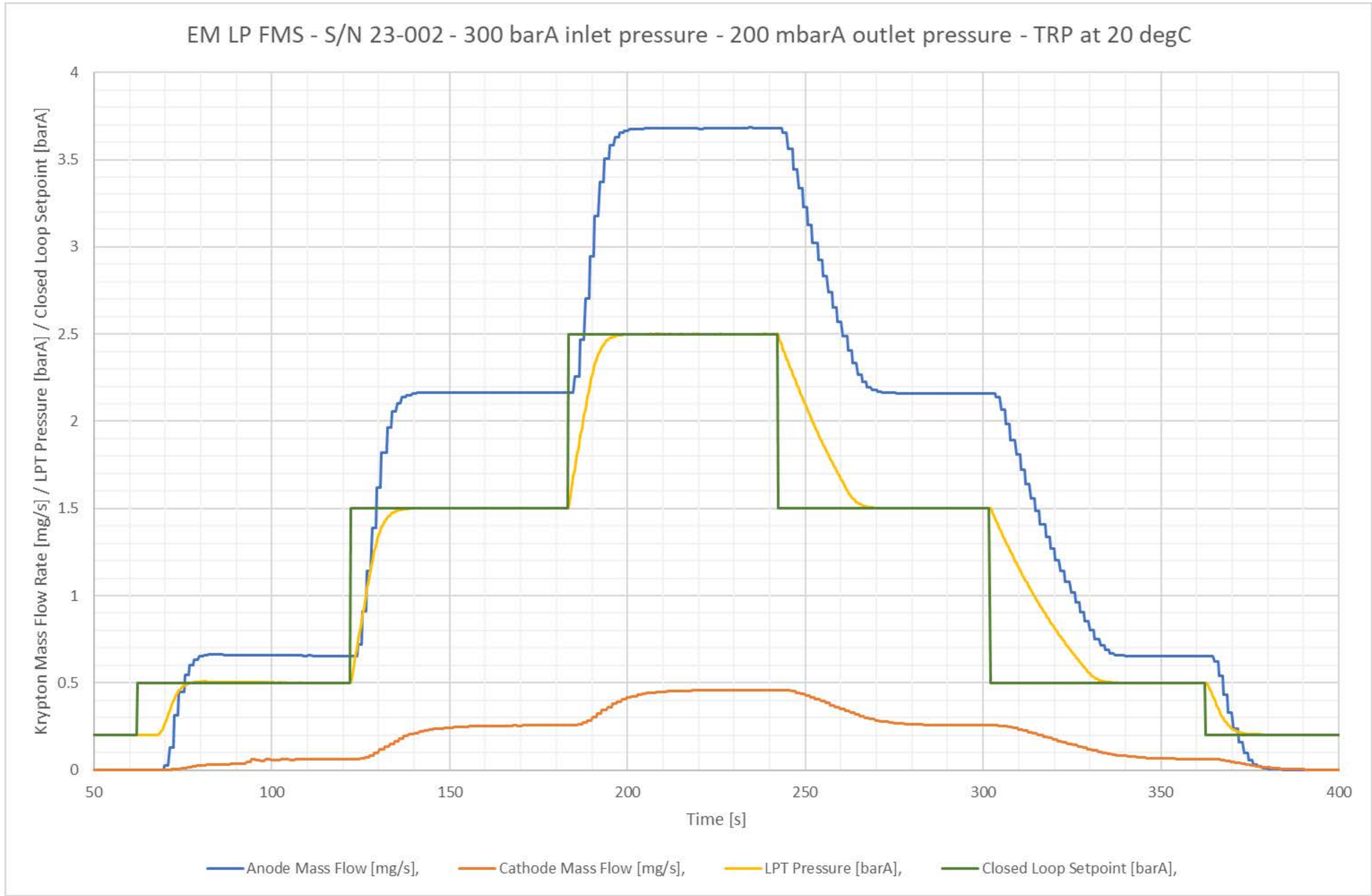
- Open loop (to ~2.5 barA LPT pressure) and closed loop (following a simple profile) test results achieved at 10 barA, 75 barA, 160 barA, 220 barA and 300 barA inlet pressure to the FMS, at 20°C TRP temperature and under vacuum conditions.
- No performance overshoots, undershoots or any other instabilities.
- Closed loop PID controller settings are the same as those used for xenon.

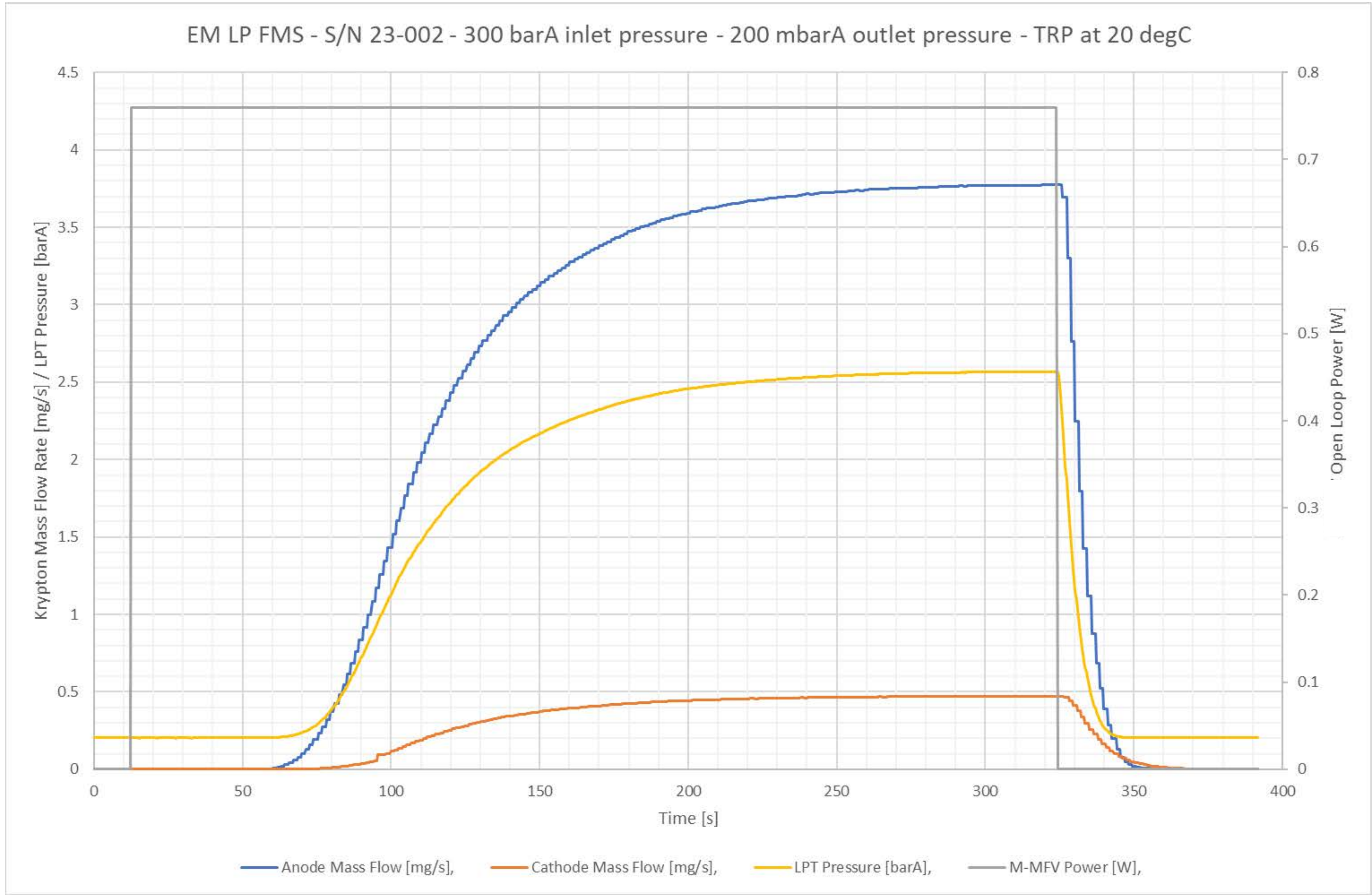




Initial krypton test results – 4 – 300 barA results

- Open loop (to ~2.5 barA LPT pressure) and closed loop (following a simple profile) test results achieved at 10 barA, 75 barA, 160 barA, 220 barA and 300 barA inlet pressure to the FMS, at 20°C TRP temperature and under vacuum conditions.
- No performance overshoots, undershoots or any other instabilities.
- Closed loop PID controller settings are the same as those used for xenon.



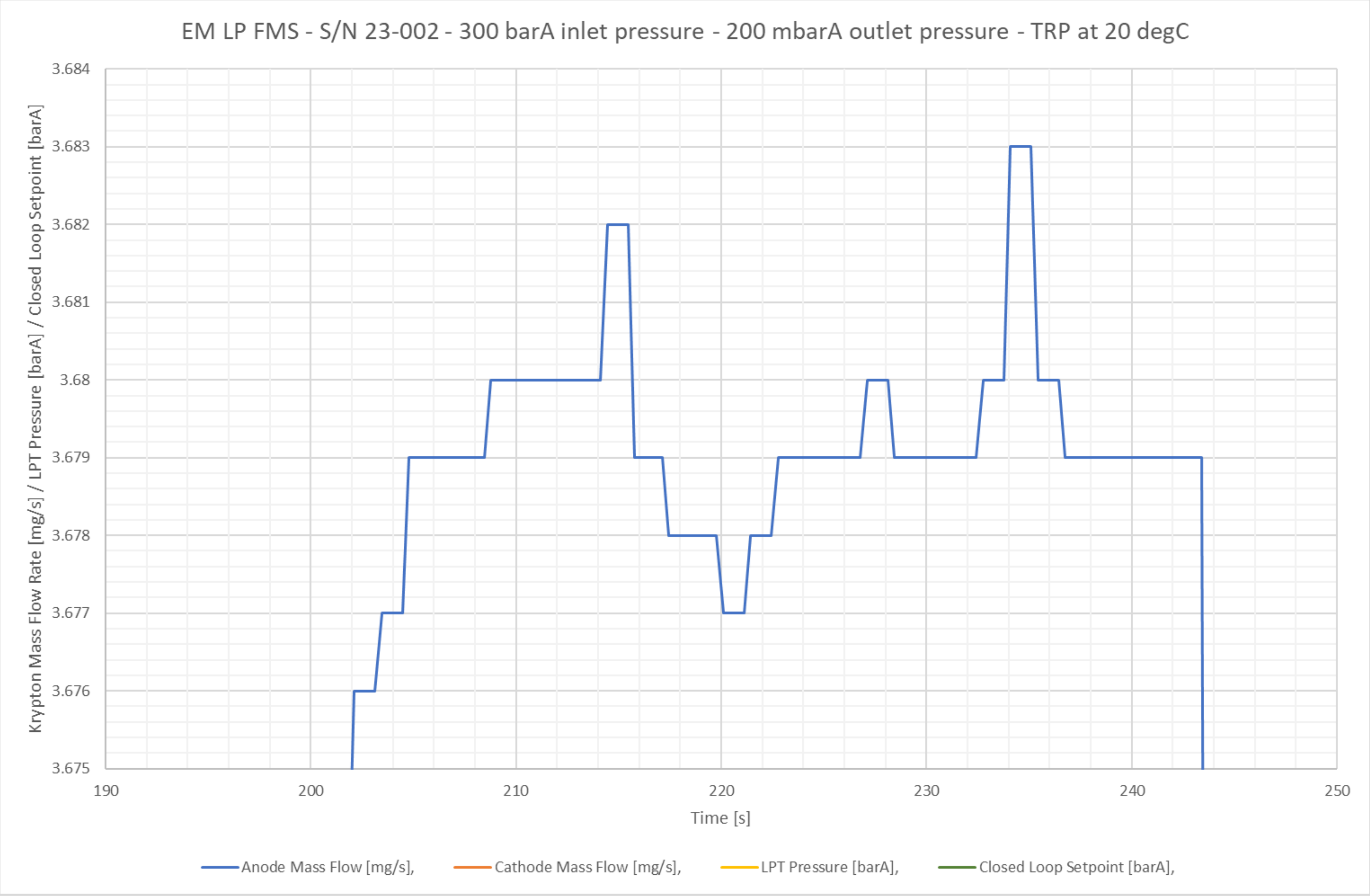


GA 101004331

Initial krypton test results – 5

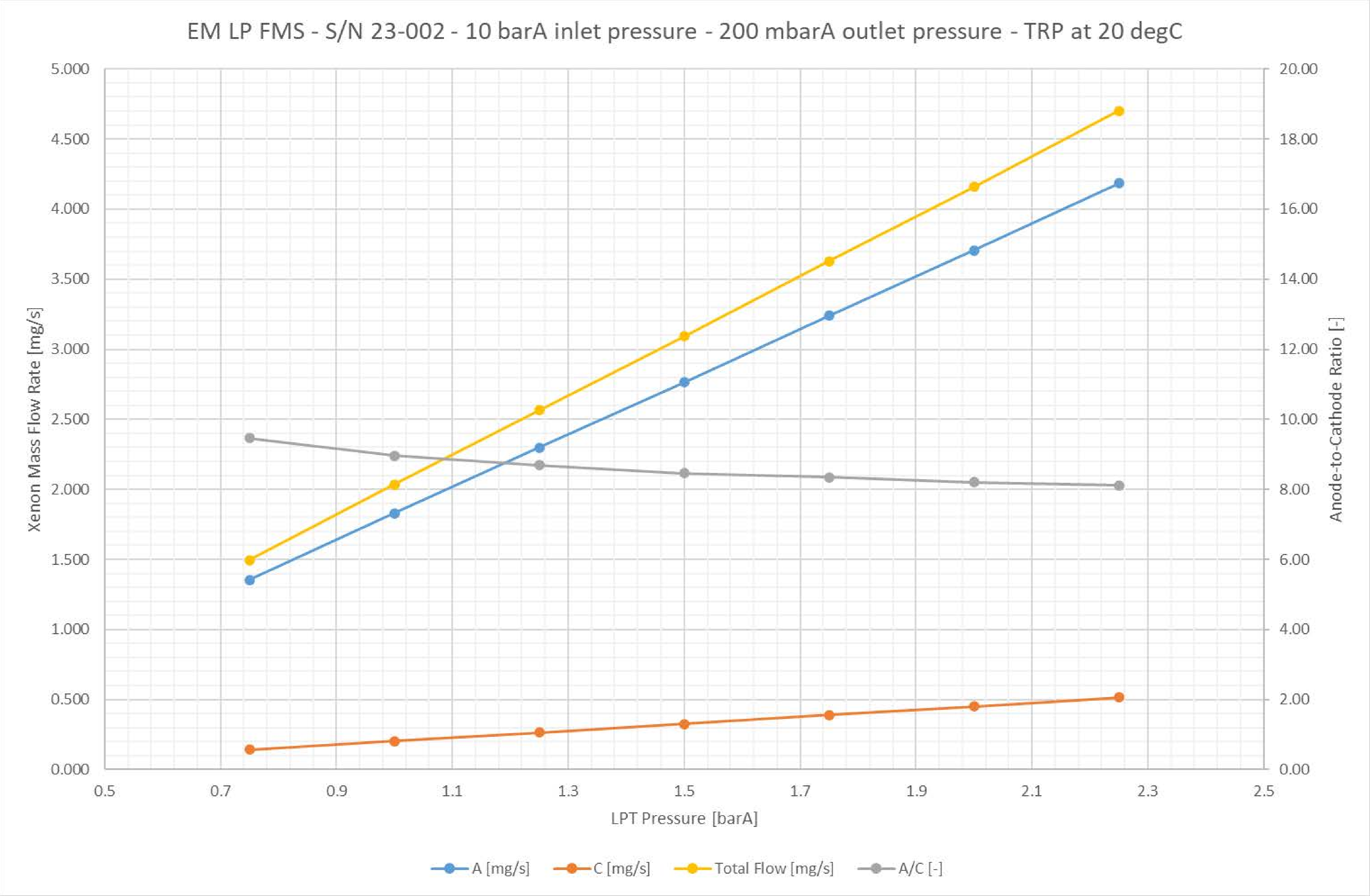
- Peak-peak flow control stability at 300 barA inlet pressure is equal to +/-0.003 mg/s krypton over 1 minute run.
- Flow sensor and data acquisition system resolution are clearly seen.
- In addition, a 300 barA inlet pressure slam-start has been performed on the FCV inlet simulating worst-case HPIV opening in-orbit. FCV performance remained unchanged.
- Flow rate data analysis shows very consistent performance as a function of inlet pressure.

	LPT Setpoint [barA]					
Flow rate [mg/s Kr]	**2.5**		**1.5**		**0.5**	
Inlet Pressure [barA]	**A**	**C**	**A**	**C**	**A**	**C**
10	3.671	0.457	2.158	0.255	0.651	0.062
75	3.675	0.457	2.160	0.256	0.651	0.063
160	3.691	0.460	2.168	0.257	0.653	0.063
220	3.687	0.458	2.165	0.257	0.653	0.063
300	3.679	0.458	2.158	0.256	0.652	0.063
Average	3.681	0.458	2.162	0.256	0.652	0.063
STD	0.008	0.001	0.004	0.001	0.001	0.000



Initial krypton test results – 6 – Xenon

- The krypton FMS was couple tested with a xenon HET without any modifications, showing the FMS versatility.



Conclusions

A high-pressure single stage fluid management system is under development at Bradford Engineering (and is currently at CDR level). One FMS is used to control the flow rate to one electric thruster (might be HET, GIE or other).

Design features include low cost, small size, low mass and simple PID controller settings, which are independent of FMS inlet pressure and medium (tested with krypton and xenon only for the moment) a feature which results in a simpler PPU design.

Initial performance results of the EMs with krypton and xenon are very positive in terms of dynamics, response times, stability, accuracy and with predictable performance and anode-to-cathode ratio, showing the versatility of the system design.

Coupled operation with a HET with xenon has been succesfully accomplished in the process of characterizing the FMS.

FMS qualification foreseen for Q3/Q4 2023.

Thank You!

This CHEOPS-LP project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004331. This presentation reflects only the Consortium's view. The EC/REA are not responsible for any use that may be made of the information it contains.

GA 101004331