



Updated cooling line stress with PP1 and bypass

Liam Cunningham

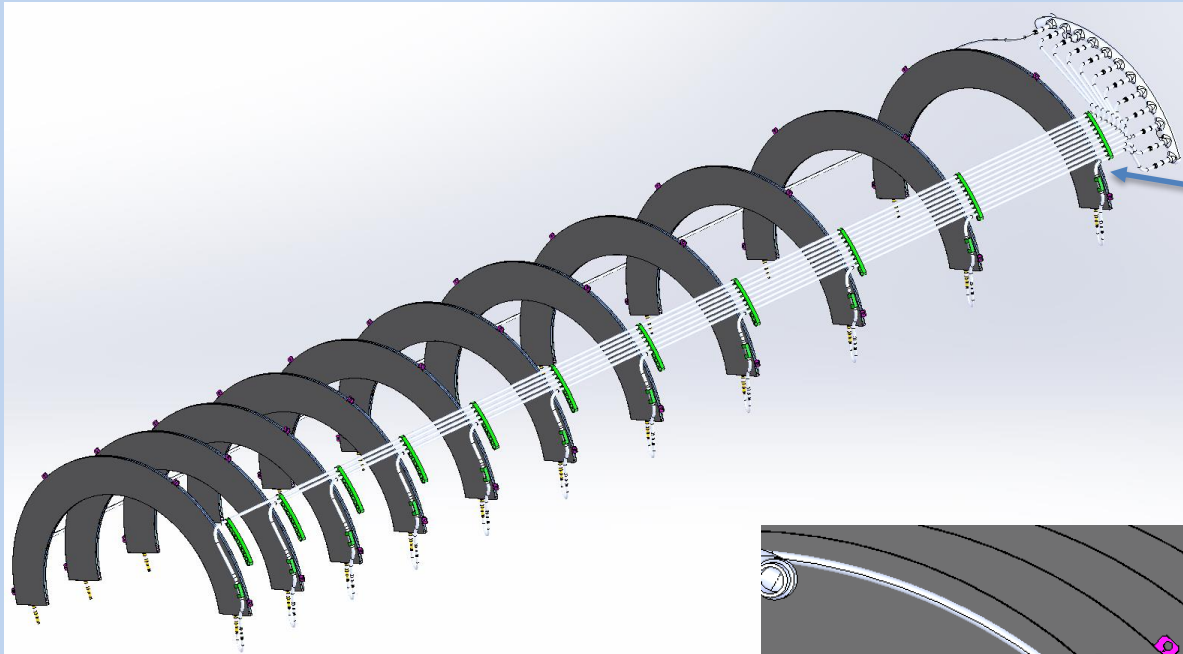
Endcap mechanics and loading F2F

10/12/2024

Most recent pipework, with new bypass line

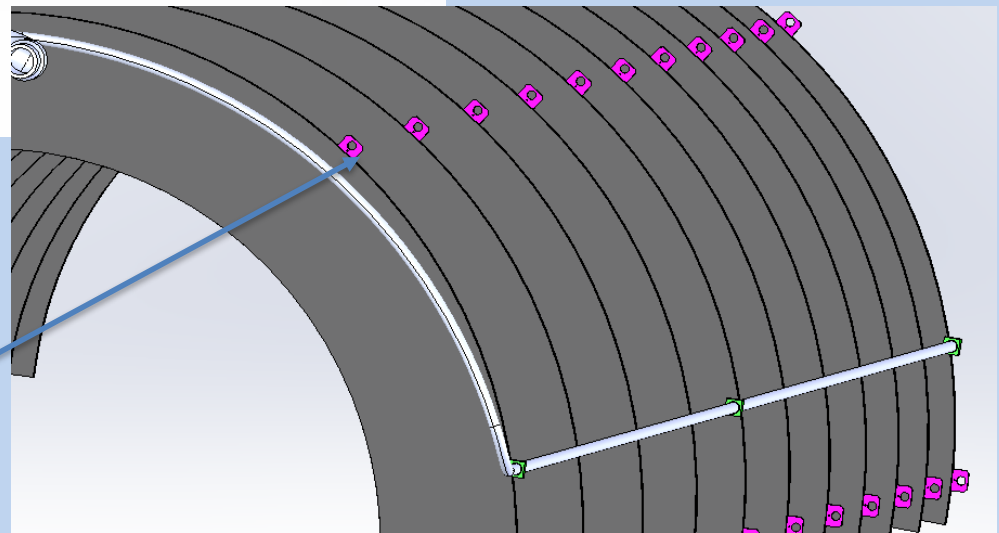


Most recent model downloaded

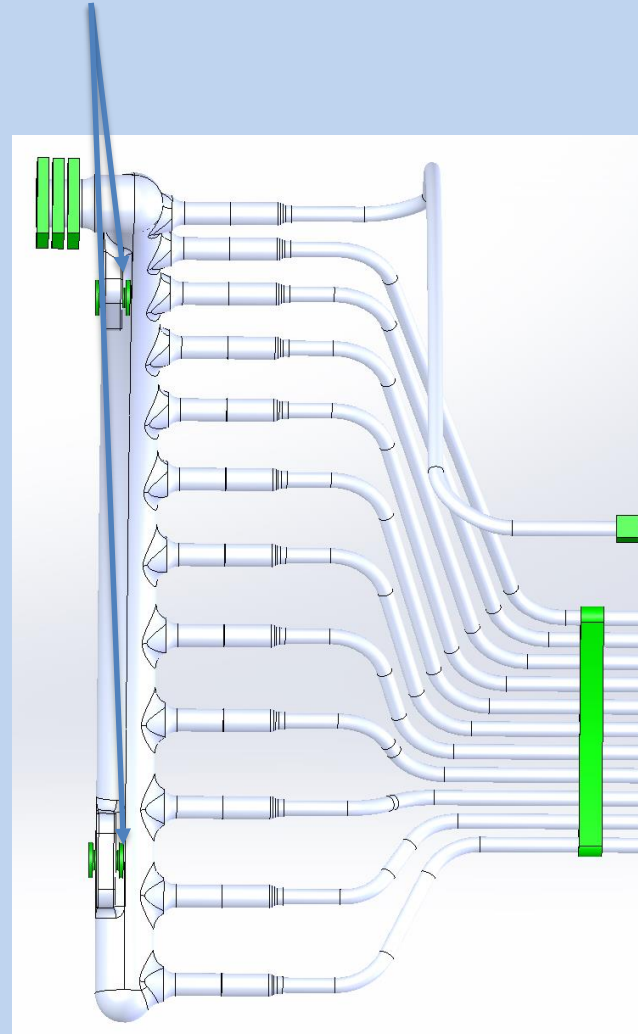
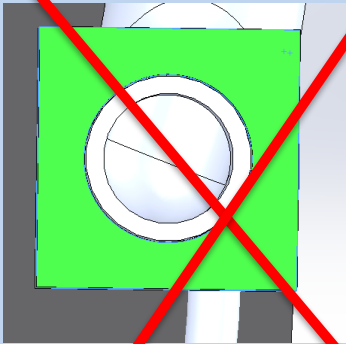


Multiline constraints
15mm from each ring-
easy to change

Half rings have cylindrical
constraints at the mounting lugs



Manifold has a Peek slider with $\pm 0.75\text{mm}$ movement on the mounting lug in Z on each mounting point

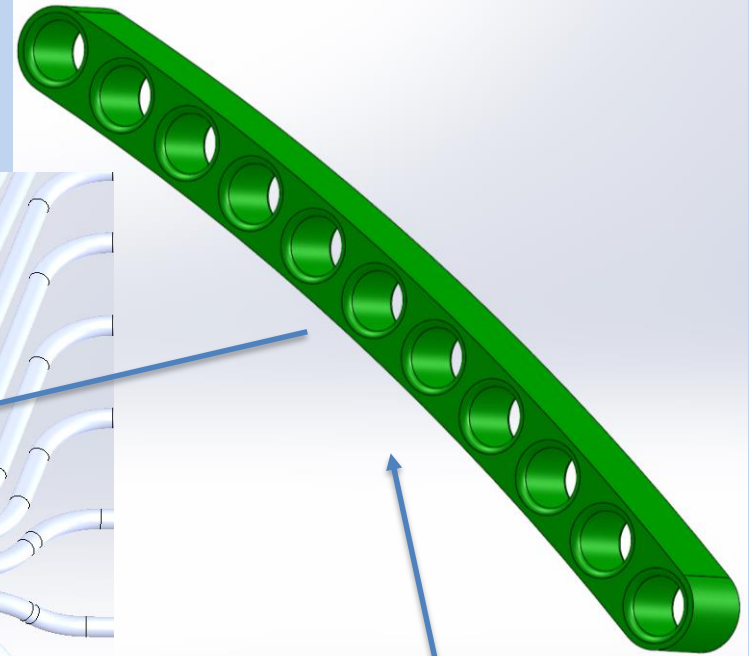
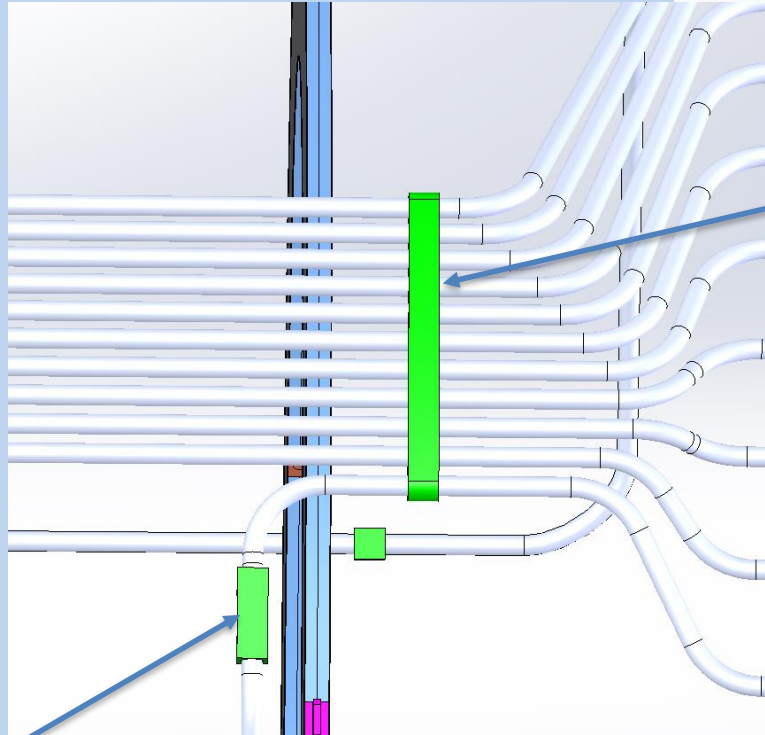
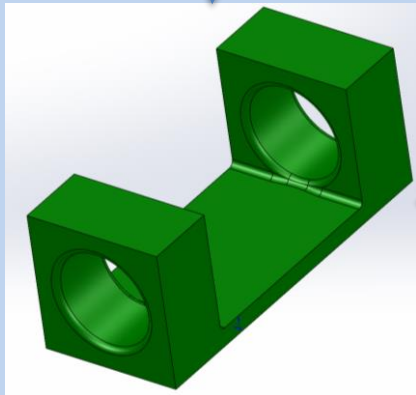


The outlet constraint has ID 12.9mm and allows movement in X,Y & Z of $\pm 0.25\text{mm}$

Not used, previously required due to imbalanced load

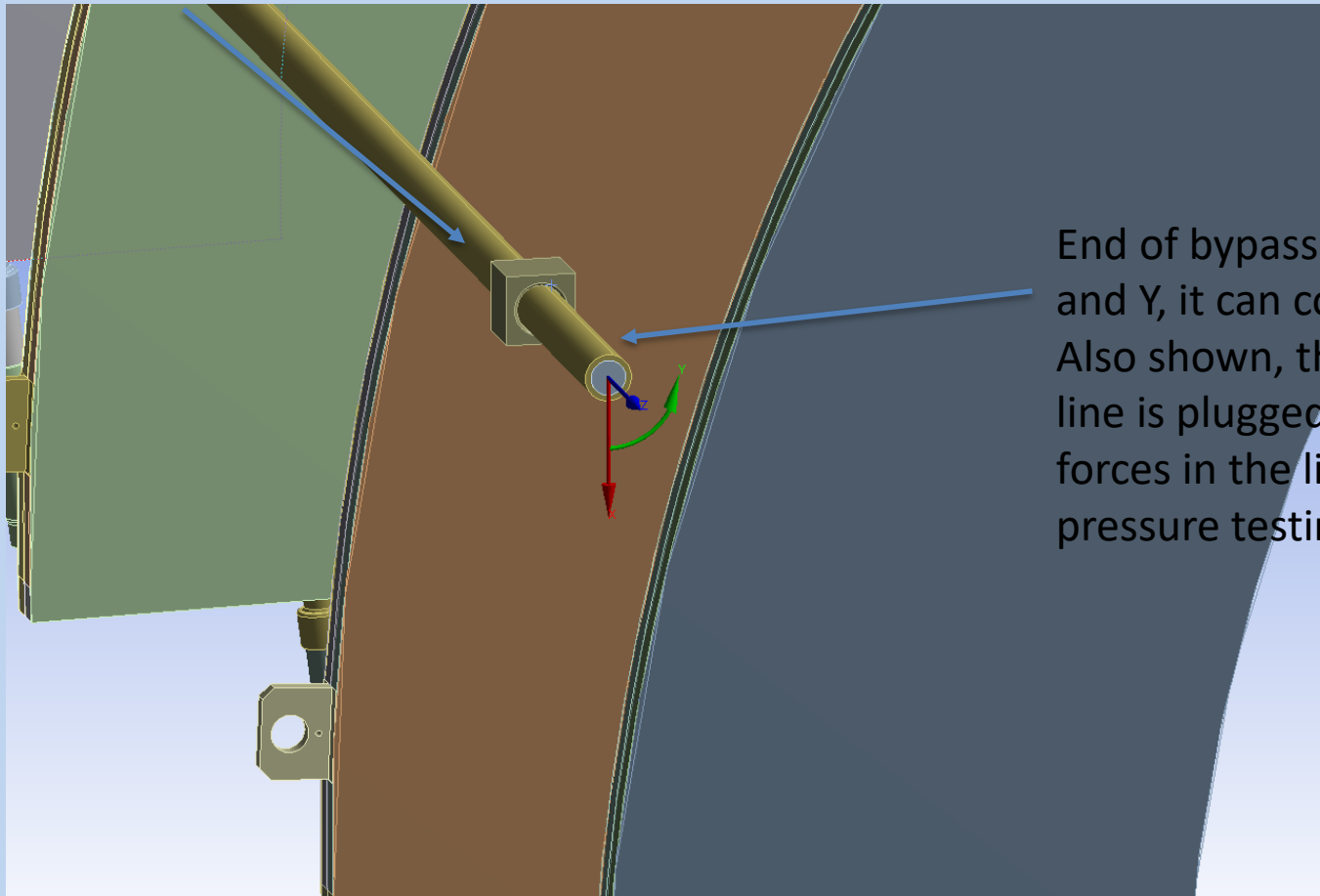
PEEK sliding contact constraints 4.2mm diameter holes, +/-
100um movement

Two edge sliding
contact to constrain
the Z movement of
the dogleg



Multiple line constraint
used on outlet lines

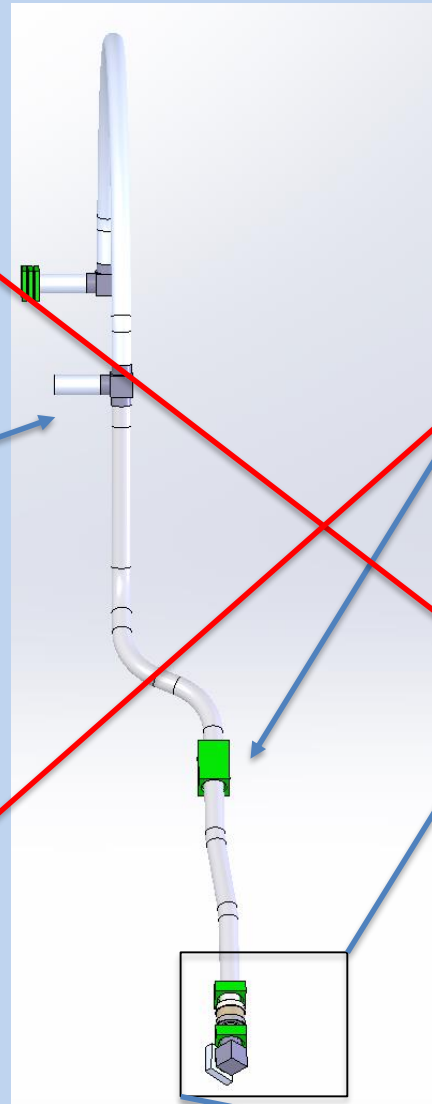
Sliding constraint 4x along length



End of bypass line is fixed in Z and Y, it can contract in X. Also shown, the end of this line is plugged to balance the forces in the lines during pressure testing.

Constraints on PP1 pipes

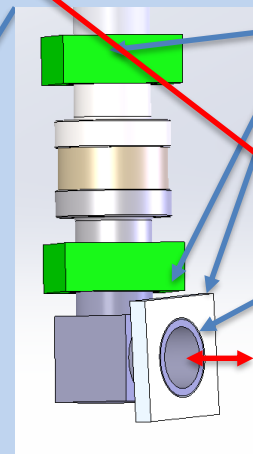
New pipework from Emiliano, December 2023



Slider constraint $\pm 250\mu\text{m}$ movement on diameter

Sliders $\pm 250\mu\text{m}$ movement on diameter

This face fixed 1 d.o.f (red arrow) all else free

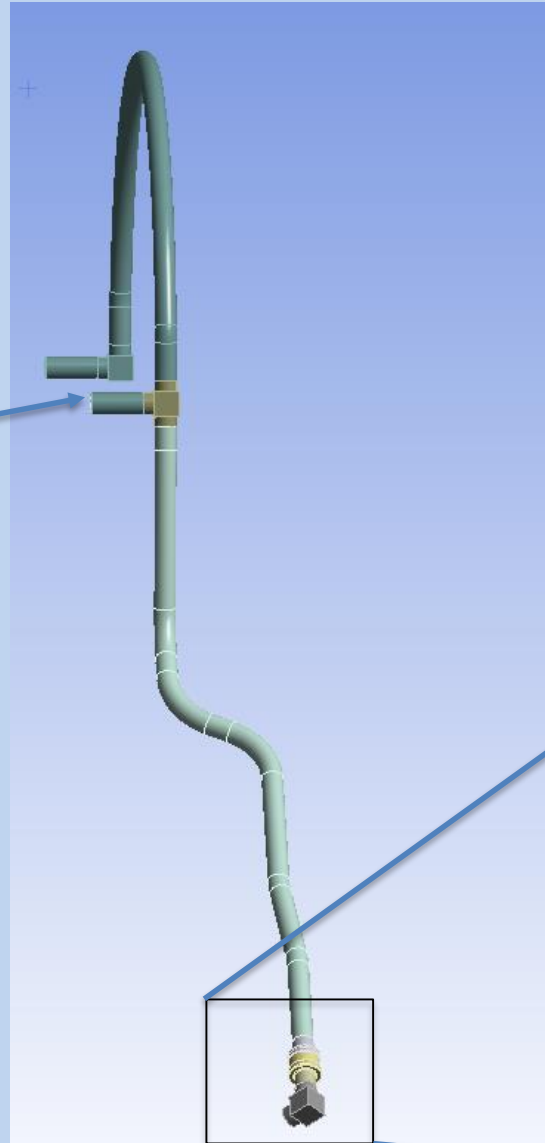
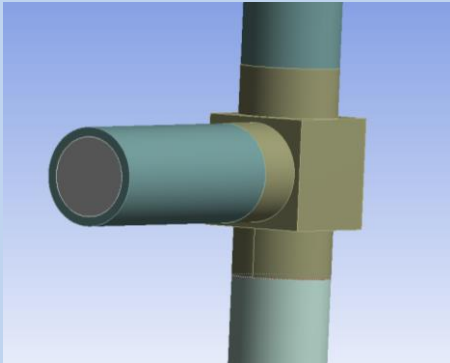


Constraint equation
So that this end moves the same as the end of the populated manifold in all 6 DOF

Updated constraints on PP1 pipes

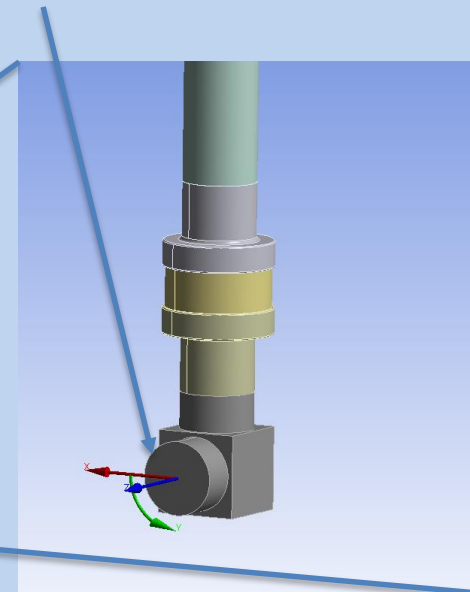
Pipework from
Emiliano, December
2023

Constraint equation
So that this end
moves the same as
the end of the
populated manifold
in all 6 DOF, open
pipe plugged



All additional constraints removed

This face fixed in Z and Y
free to contract in X. Open
end plugged



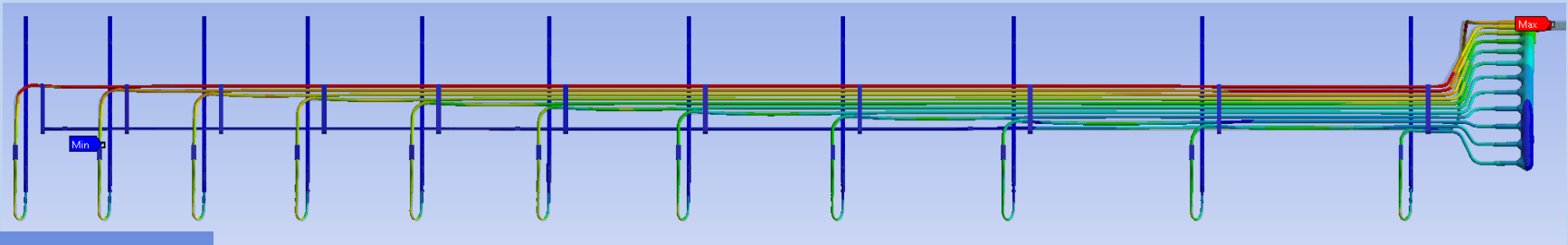


Load cases for models

- Load case 1: 162 bar 22°C
 - Initial pressure proof load
- Load case 3: 14 bar -40°C
 - Supply temp and pressure during operation before power up
- Load case 3: 0 bar -55°C
 - Failure mode/ potential shipping load

162bar pressure load on LH pipe run

Total displacement (X,Y,Z)



S: Copy of Copy of Copy of

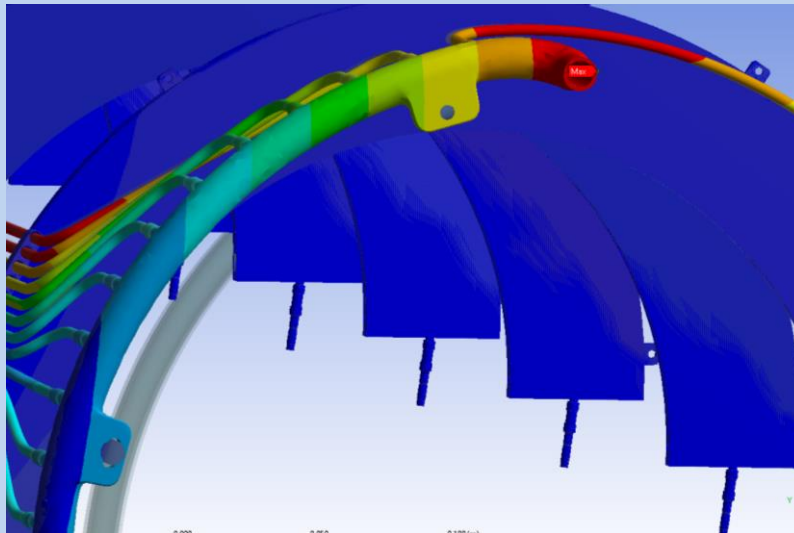
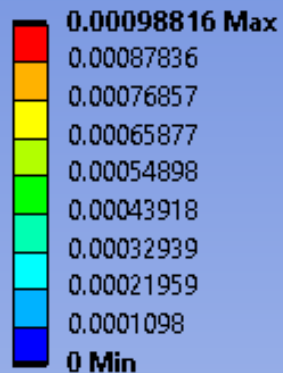
Total Deformation 5

Type: Total Deformation

Unit: m

Time: 1

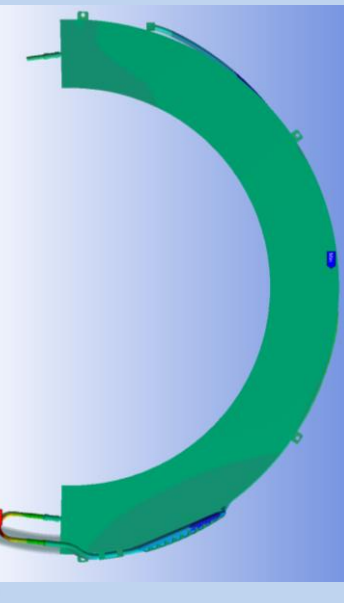
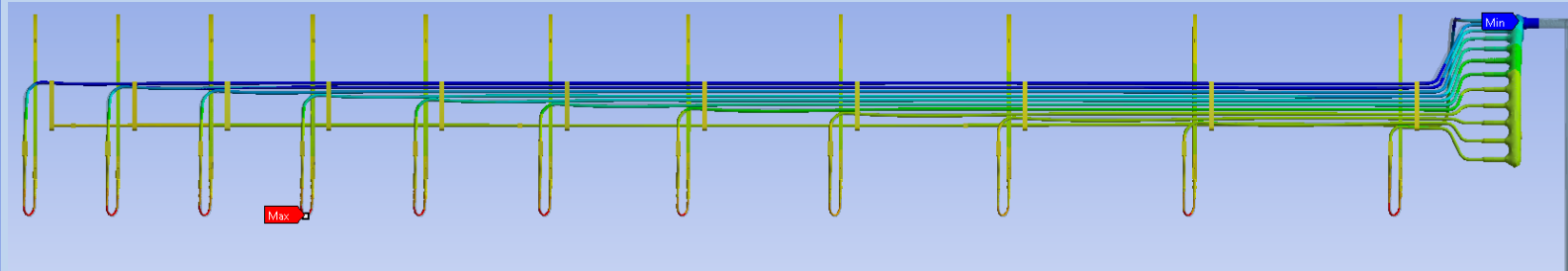
30/07/2024 16:23



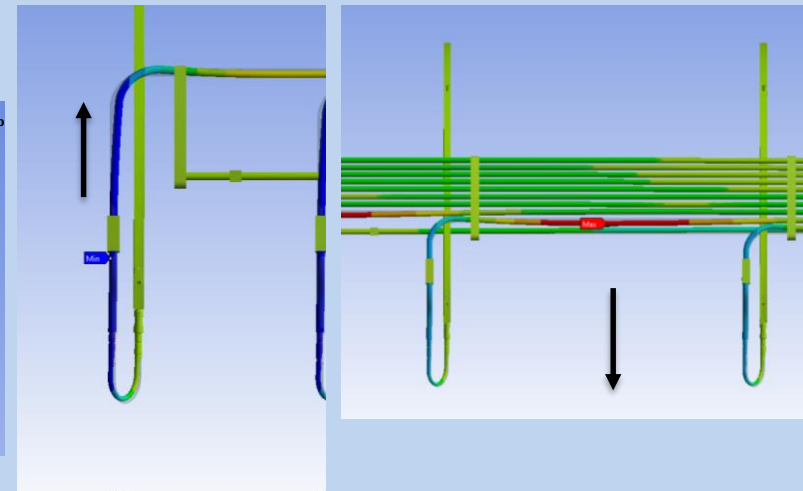
Maximum displacement at the manifold attach point

162bar pressure load on LH pipe run

Z-displacement. U-bends push forward manifold end push back



Y-displacement of ring 1 pipes, U-bend moves out $\sim 0.5\text{mm}$



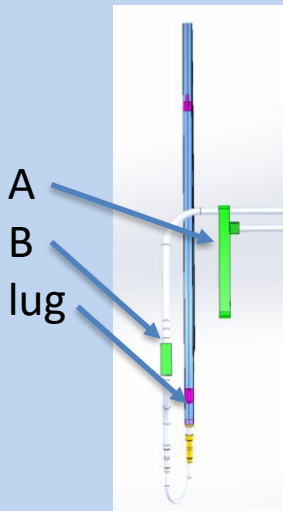
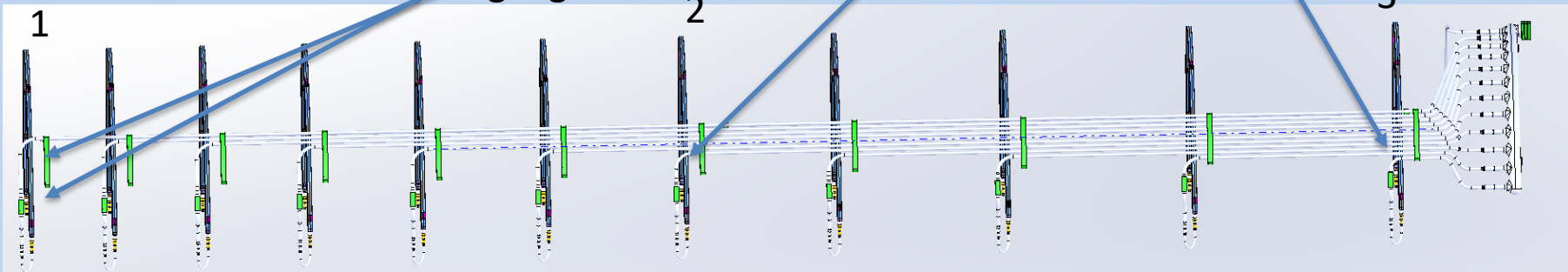
X-displacement of pipes, bending up and down $\sim 0.5\text{mm}$

162bar pressure load on LH pipe run

Reaction forces on constraints are all low

Measure both pipe constraints at low-z ring, middle ring and high-z ring and on the manifold.

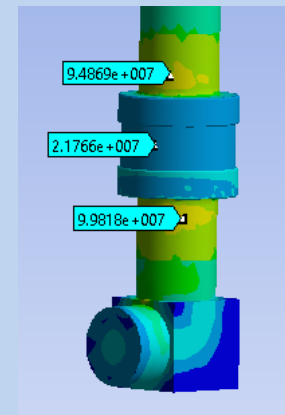
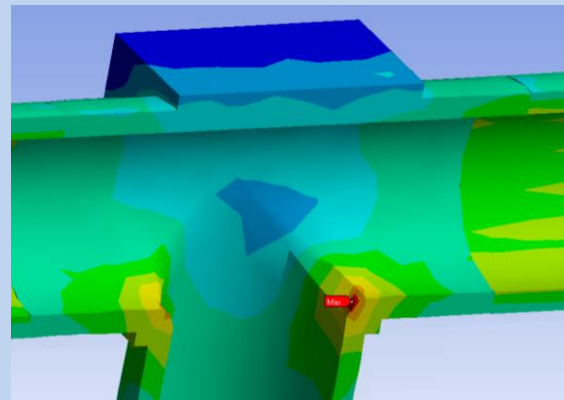
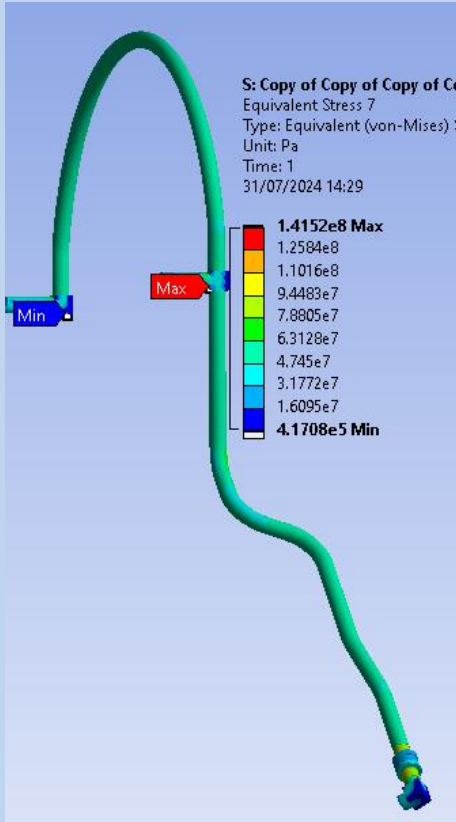
Also looked at reaction force on the low Z ring lug



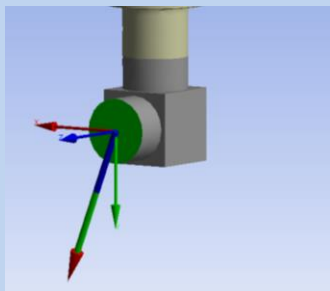
constraint	X-force(N)	y-force(N)	z-force(N)	Combined(N)	Combined Moment (Nm)
A1	19.481	8.1375	-9.43E-08	21.112	0.12
B1	9.9991	-10.503	-0.79395	14.523	0.23
A2	22.43	6.5125	5.27E-09	23.356	5.4e-2
B2	4.632	-10.877	-10.979	16.134	5.3e-3
A3	24.005	2.4049	2.81E-04	24.125	0,16
B3	3.7355	-9.4936	-12.902	16.448	0,11
Lug	-2.63	-2.3302	-8.09e-002	3.52	2.5e-2

162bar pressure load on PP1 pipe

Stress concentration shows as peak of 142MPa on inner corner of T-cube. Stresses on EB area are under 100MPa
Average stress ~59 MPa on all PP1 pipes.



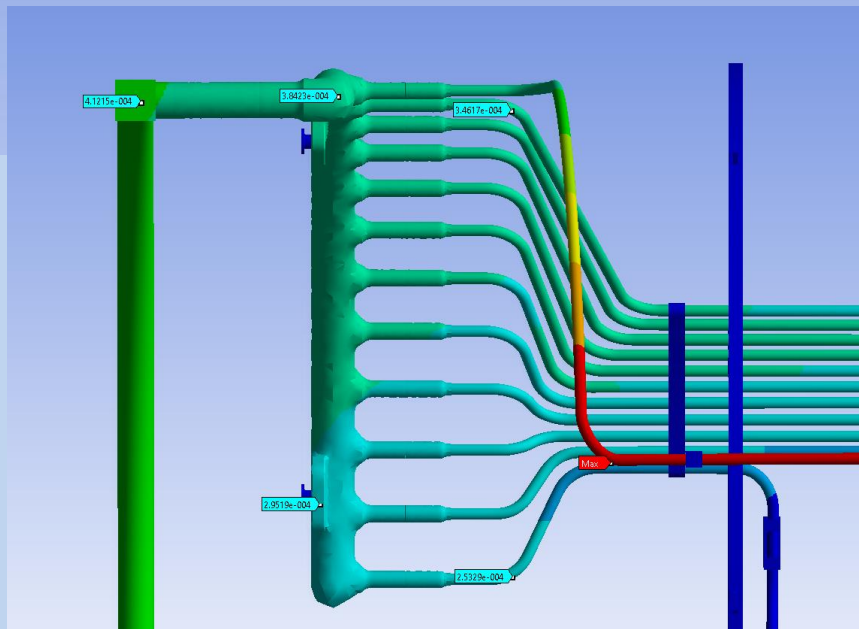
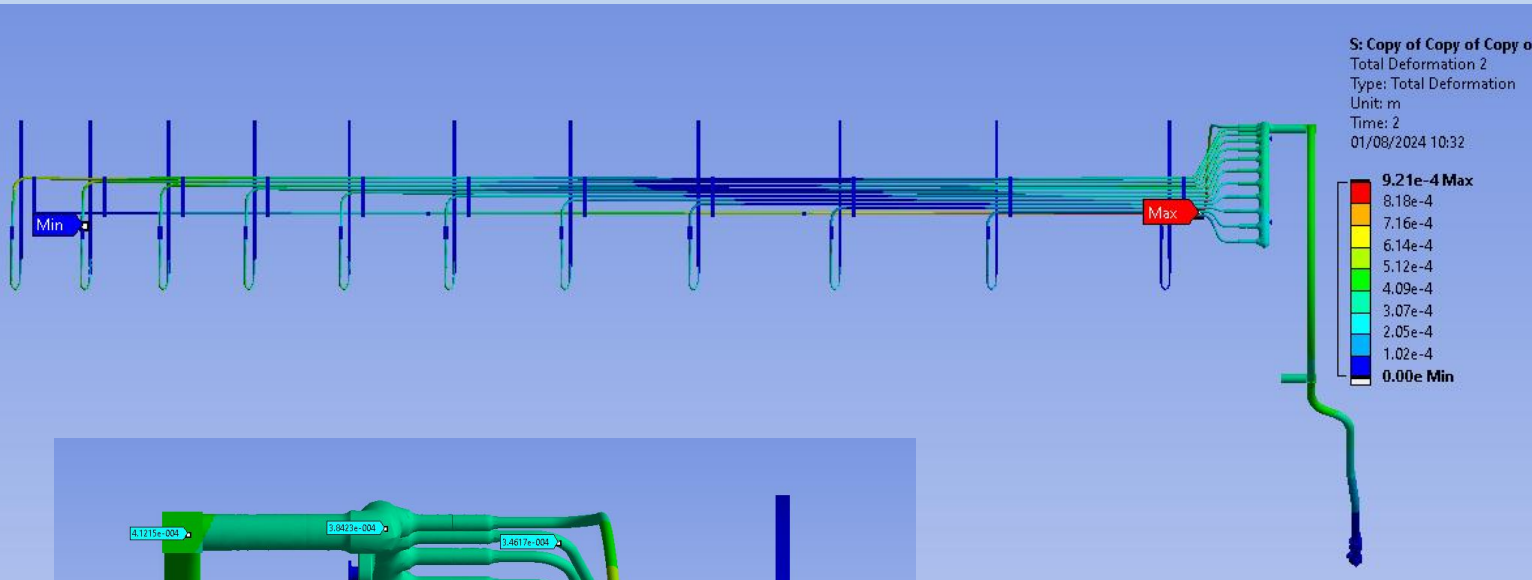
Only one constraint, at the PP1 to flex line attach, EB looked at separately. Force components use the coordinate system below left, all are very low.



	X (N)	Y(N)	Z(N)	Combined(N)	Combined Moment (Nm)
1	-6.7925	32.83	8.9432	34.697	2.4

14 bar -40°C: total deformation

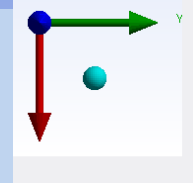
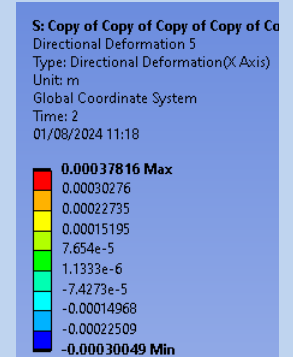
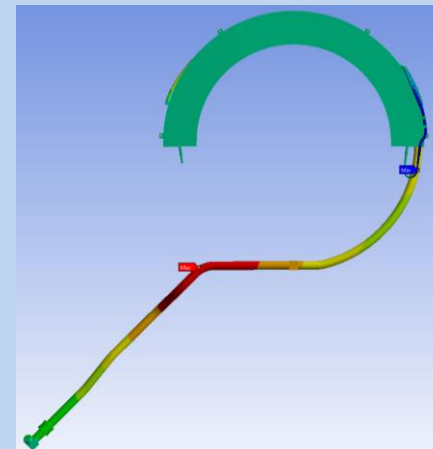
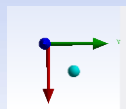
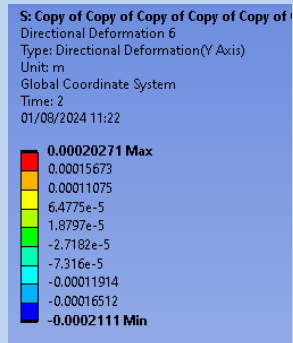
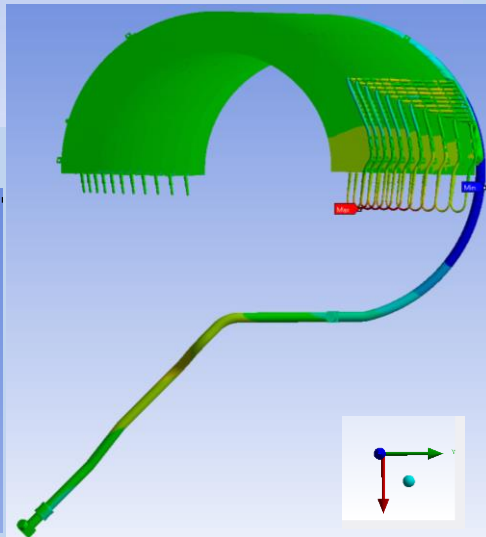
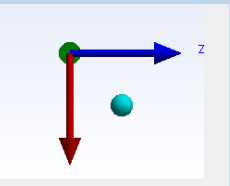
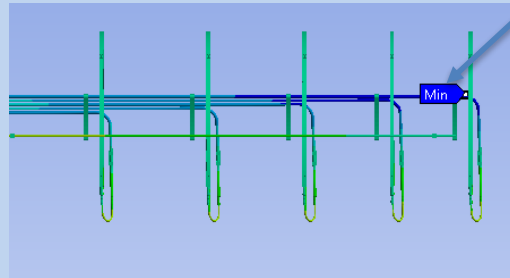
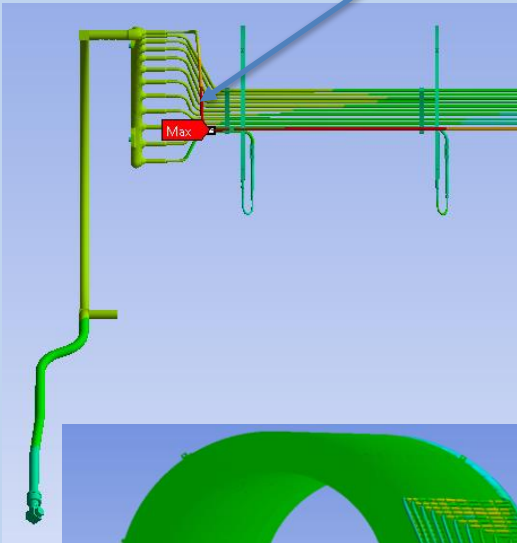
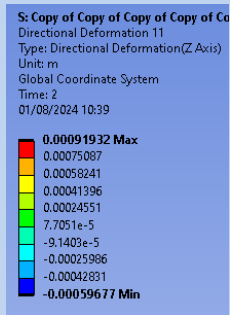
Total deformation (X,Y,Z combined)



As might be expected largest movement is the bypass line, $\sim 920\mu\text{m}$. All other movements $< 500\mu\text{m}$

14 bar -40°C: directional deformation

By pass line moves 0.9mm in +ve Z end of ring 1 line moves 0.6mm in -ve Z

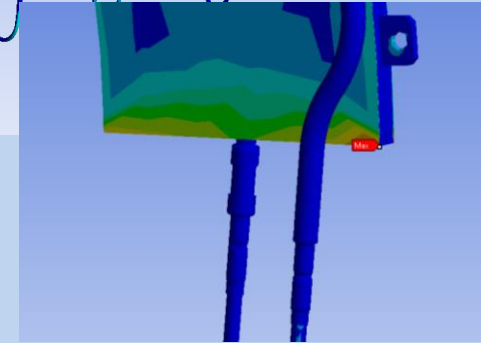
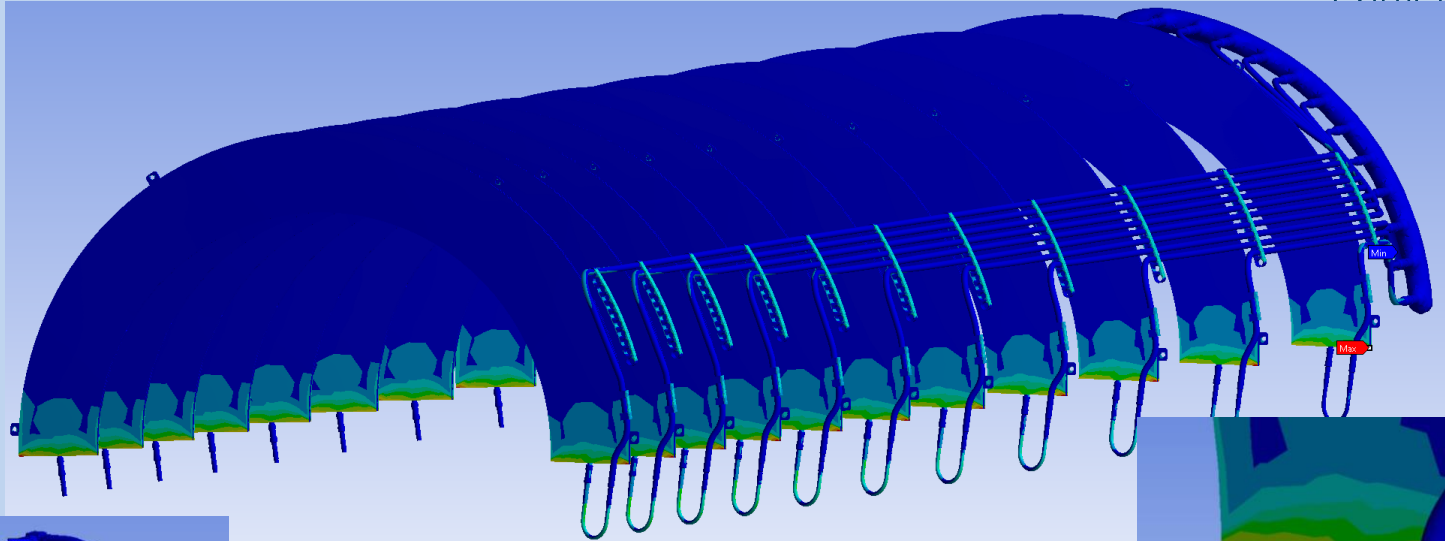
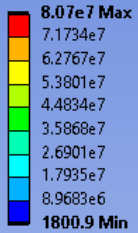


X-displacement, maximum $\pm 300\mu\text{m}$

Y-displacement, maximum $\sim \pm 200\mu\text{m}$

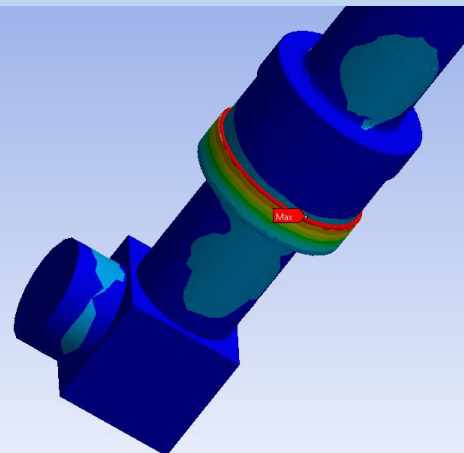
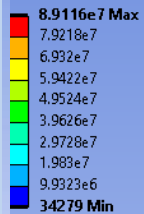
14 bar -40°C: stresses

S: Copy of Copy of Copy of
Equivalent Stress 2
Type: Equivalent (von-Mis
Unit: Pa
Time: 2
01/08/2024 11:28



Maximum stress in pipe is in the CF skin
~81MPa, average stress 6MPa

S: Copy of Copy of Copy of Copy of C
Equivalent Stress 5
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 2
01/08/2024 11:31



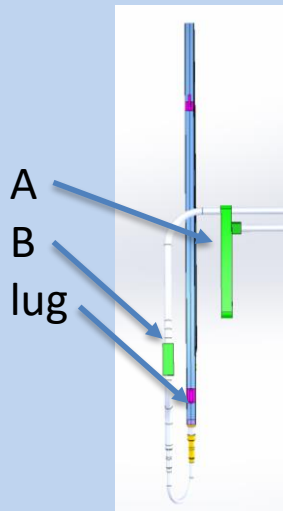
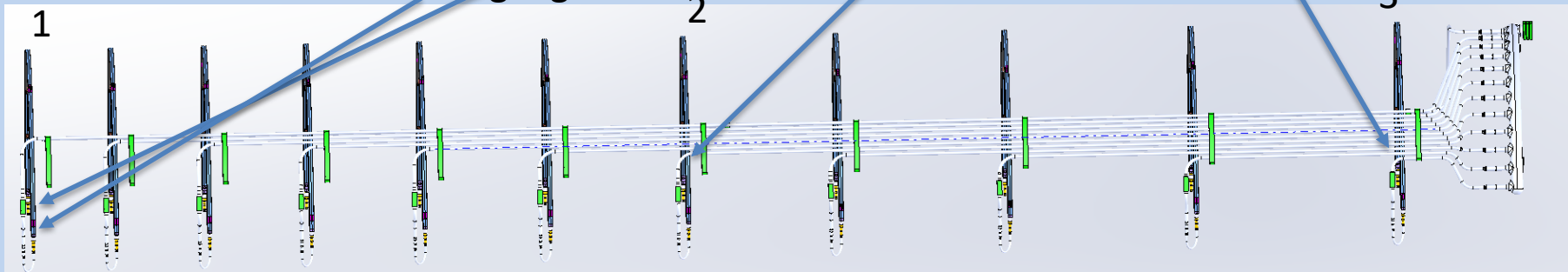
Maximum stress is SSTL cup on EB
~89MPa, max pipe stress average
stress 7MPa

14 bar -40°C reaction forces

Reaction forces on constraints are all low

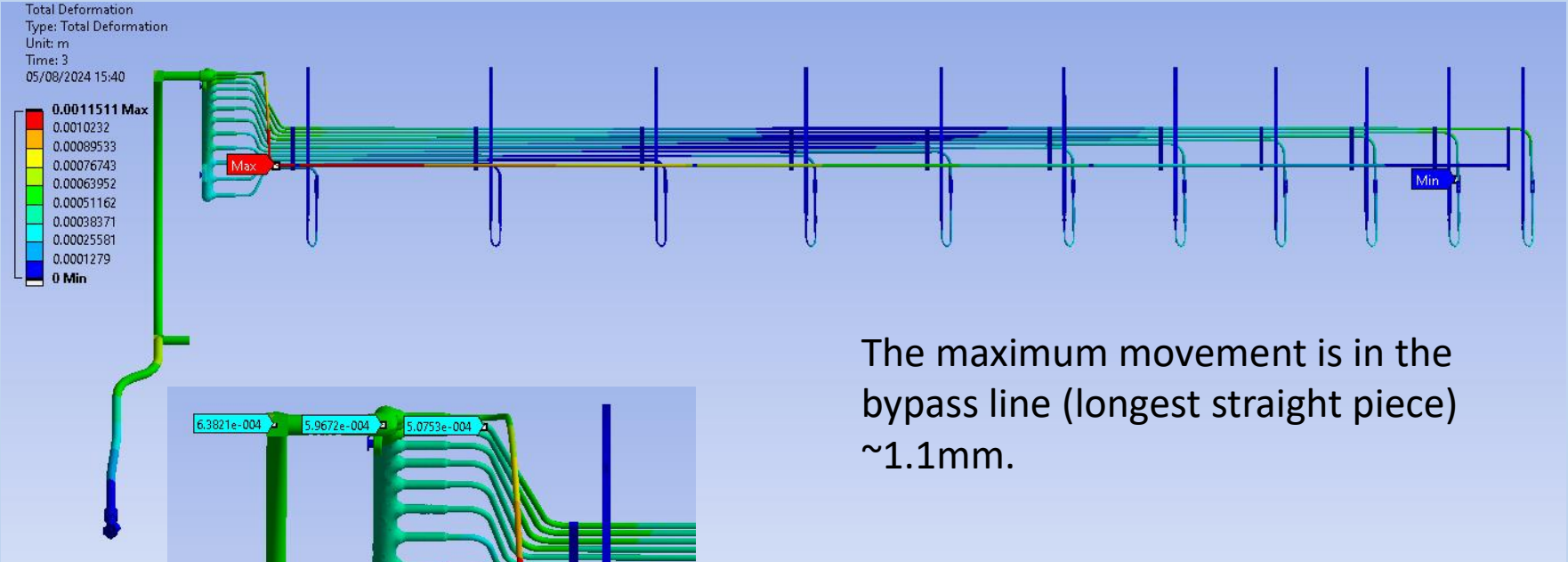
Measure both pipe constraints at low-z ring, middle ring and high-z ring and on the manifold.

Also looked at reaction force on the low Z ring lug

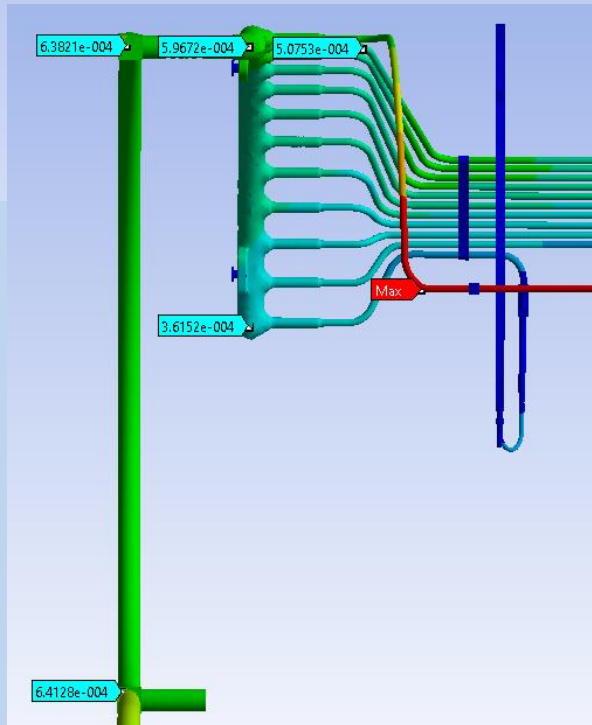


constraint	X-force(N)	y-force(N)	z-force(N)	Combined(N)	Combined Moment (Nm)
A1	0.80	0.42	3.7e-6	0.90	3.1e-3
B1	0.19	0.19	1.76	1.78	0.02
A2	0.49	0.11	5.5e-6	0.50	1.3e-3
B2	0.11	-0.02	0.99	0.99	0.01
A3	8.10	7.97	1.2e-5	11.37	0.07
B3	0.71	-1.37	-6.22	6.41	0.06
Lug	21.67	12.42	-0.81	24.98	0.02
PP1 end	7.98	22.16	-0.50	23.56	1.48

-55°C-total deformation



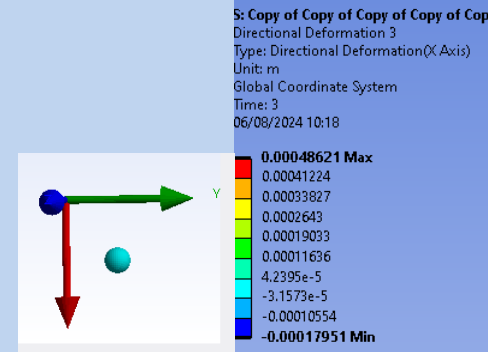
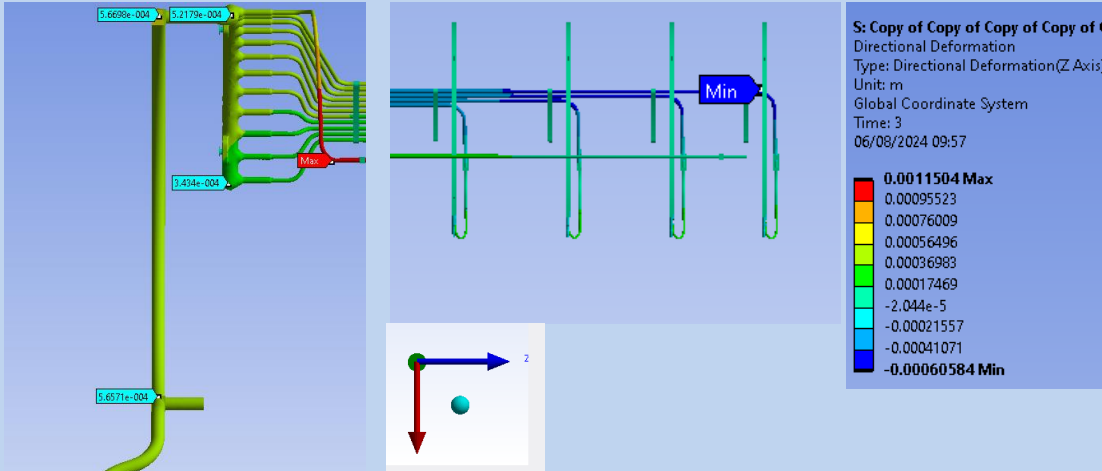
The maximum movement is in the bypass line (longest straight piece) ~1.1mm.



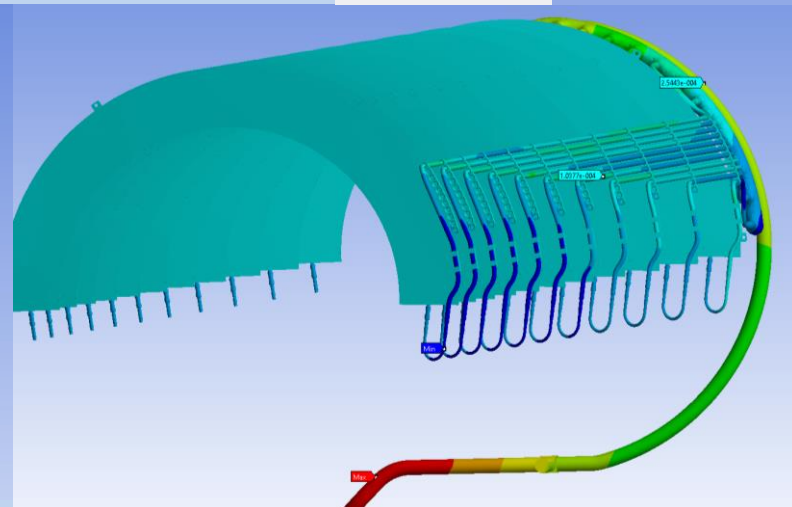
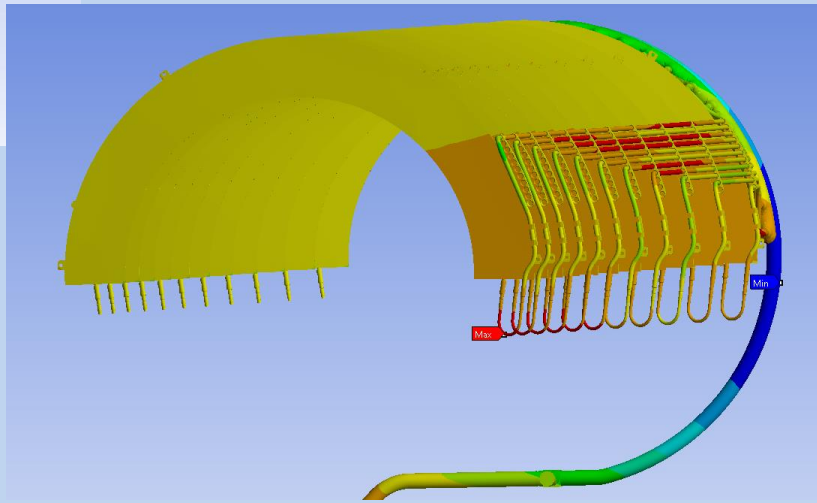
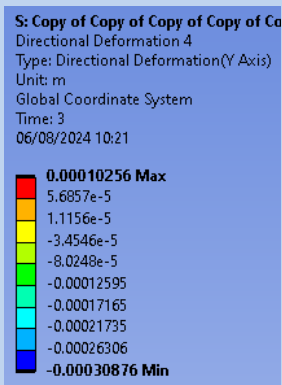
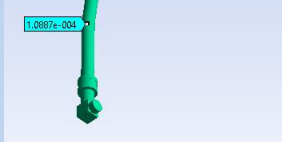
Manifold moves at an angle, PP1 loop stays ~parallel. Longest outlet line (Ring 1) moves ~0.5mm

-55°C-directional deformation

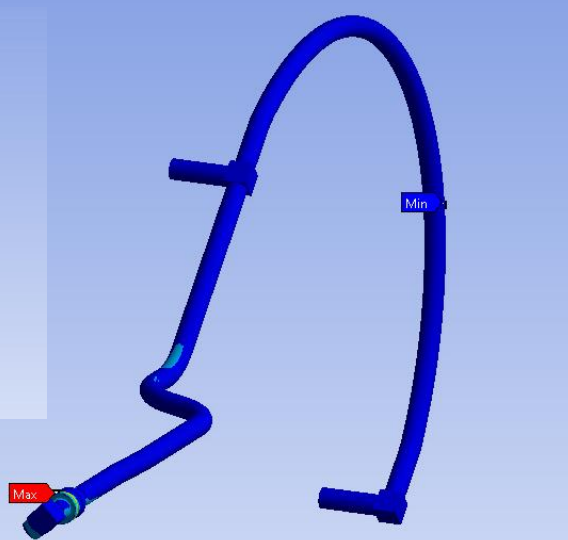
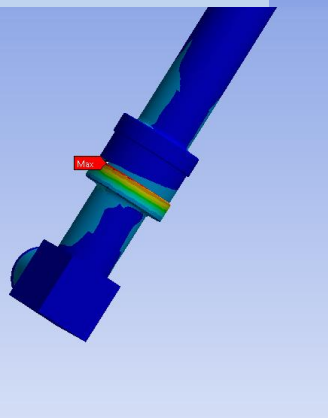
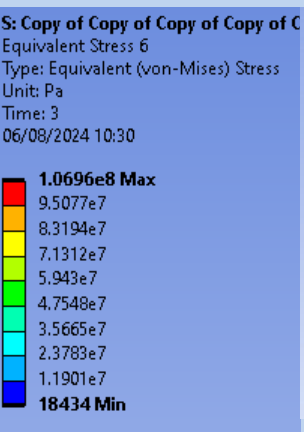
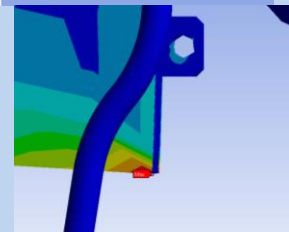
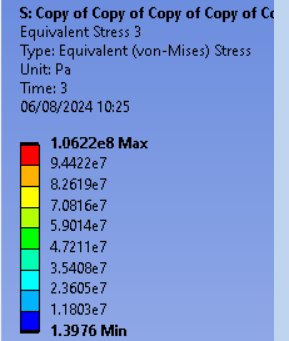
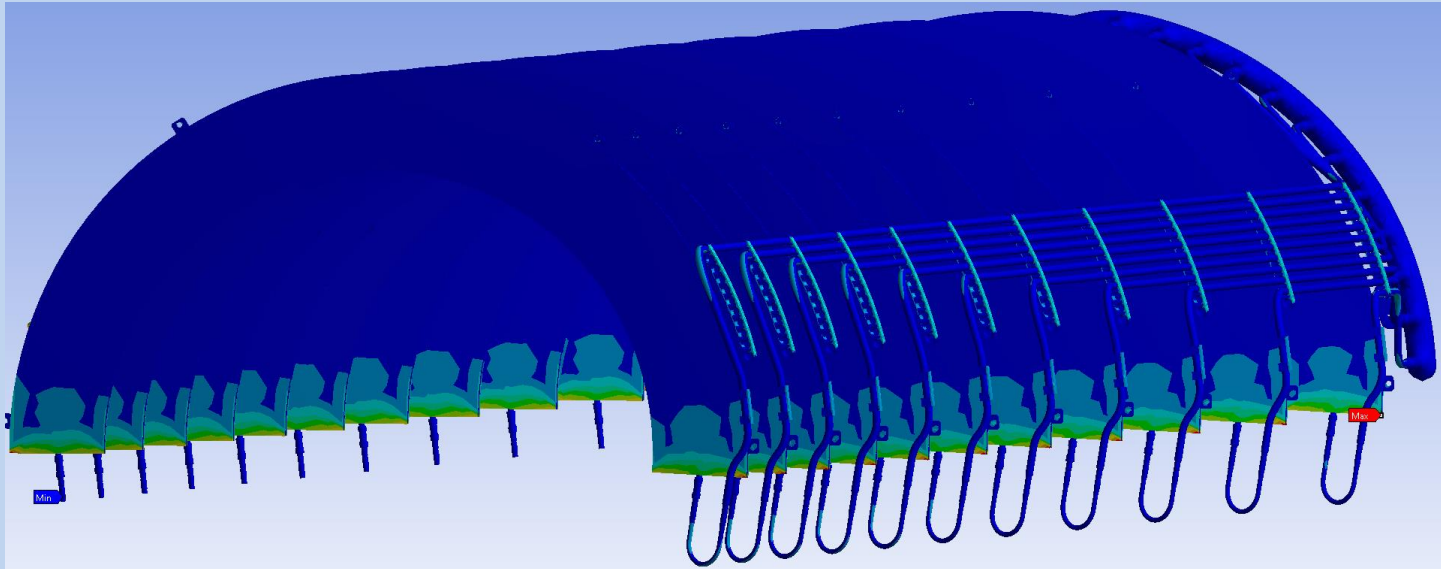
Bypass line has largest Z-movement, +ve 1.15mm outlet line for ring 1 has largest -ve 0.6mm. Other movements $\pm \sim 0.5\text{mm}$



Maximum X and Y movements <0.5mm



-55°C-Stresses



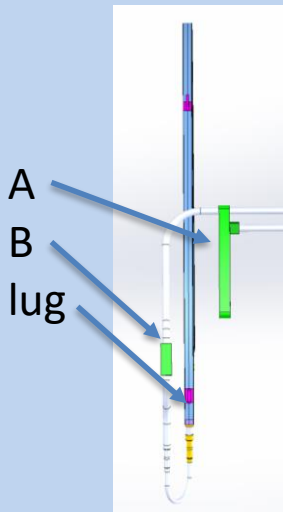
Maximum stresses caused by CTE mismatch, 106MPa in the CF skin in the local supports and in the SSTL cup on the PP1 E-break. Average stresses all <6MPa

-55°C reaction forces

Reaction forces on constraints are all low

Measure both pipe constraints at low-z ring, middle ring and high-z ring and on the manifold.

Also looked at reaction force on the low Z ring lug



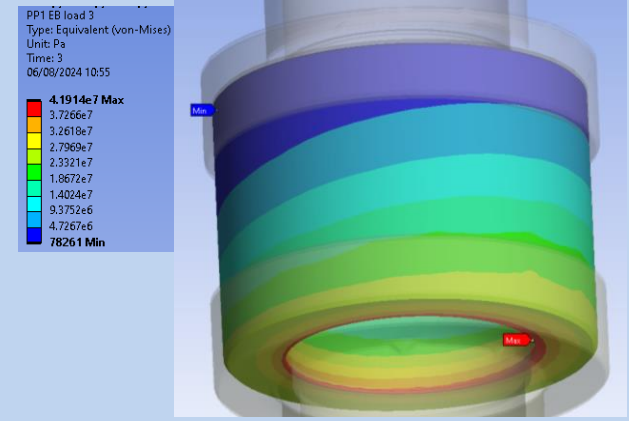
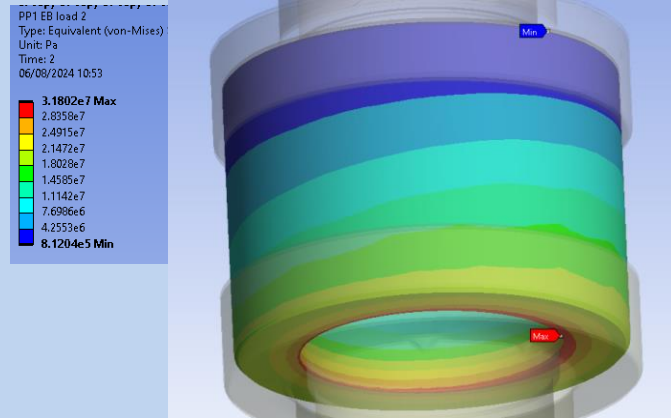
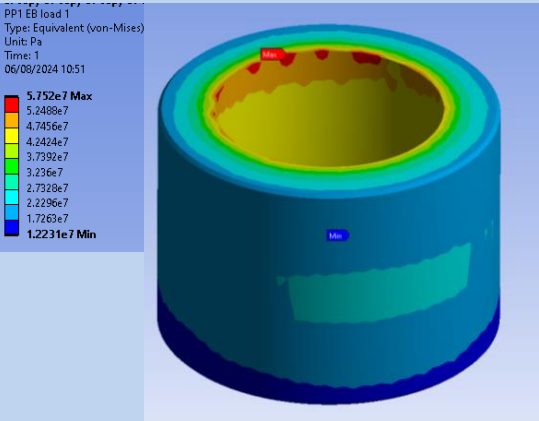
constraint	X-force(N)	y-force(N)	z-force(N)	Combined(N)	Combined Moment (Nm)
A1	-0.43	-0.38	-5.16E-06	0.58	2.65E-03
B1	0.11	1.12	2.35	2.60	2.28E-02
A2	-0.85	-0.45	-3.98E-06	0.96	2.62E-03
B2	0.44	0.45	2.62	2.70	3.44E-02
A3	9.92	11.19	3.32E-06	14.95	9.76E-02
B3	0.53	-0.75	-6.55	6.61	5.91E-02
Lug	27.79	17.02	-0.77	32.60	1.23E-02
PP1 end	11.81	27.56	-2.13	30.06	2.26

Loads on PP1 EB

~57.5 MPa at 162 bar

~32 MPa at -40°C 14 bar

~42 MPa at -55°C



Stresses and reactions are all low for the EB now the unbalanced load has been corrected.

The maximum stress in cases 2 and 3 is caused by the CTE mismatch of SSTL and ceramic.

Reaction forces and moments

	X (N)	Y (N)	Z (N)	Combined (N)	Combined Moment (Nm)
162 bar	4.64E-06	-9.45E-06	5.20E-06	1.17E-05	2.16E-02
14 bar -40°C	-3.80E-06	-3.50E-06	2.66E-06	5.81E-06	2.49E-02
-55°C	-8.86E-07	-4.32E-06	1.00E-06	4.52E-06	2.97E-02



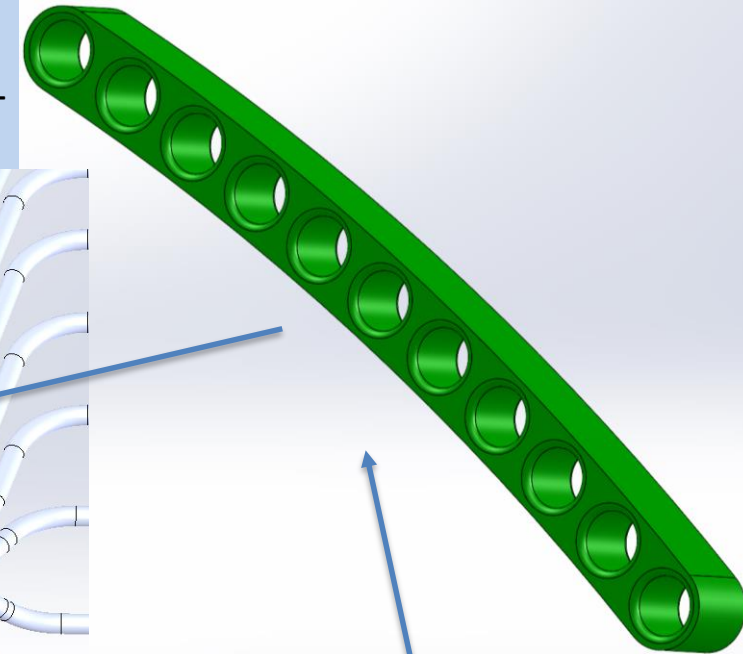
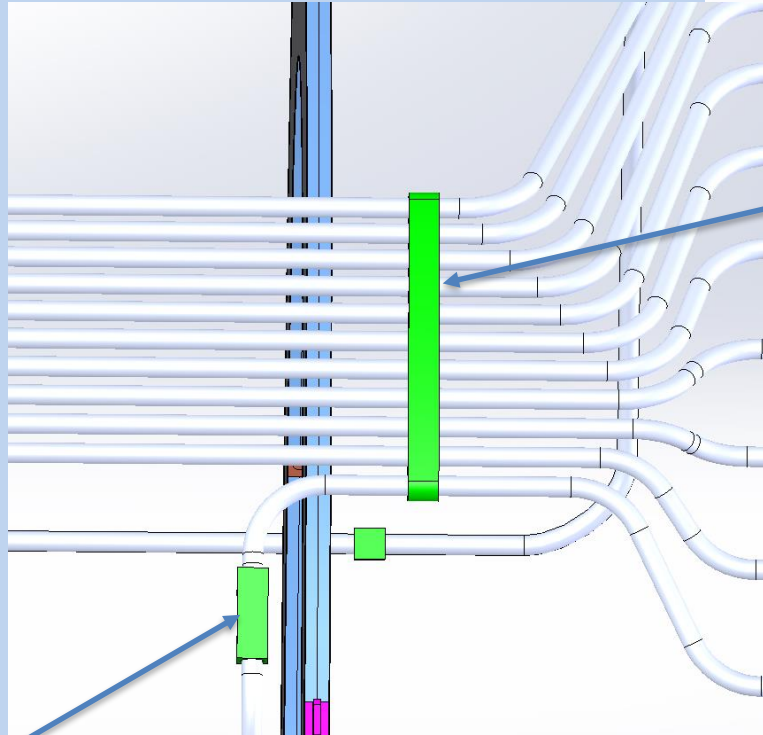
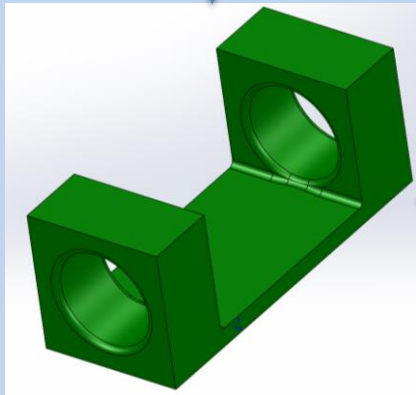
Summary 1

- The cooling loops inside the L2 Endcap all demonstrate low stress and minimal movement under all regimes
 - The inlet line is not included, likely to behave similar to the bypass line
- Fixing the unbalanced pressure load (blanking off the open pipe ends) has solved the problem of large reaction forces at the end points.
 - No large movements
- Stresses are all low, maximum stress across the 3 load regimes is ~177MPa at 162 bar
 - ~65% of minimum yield stress (275MPa)
 - All other stresses are low
- Stresses and forces on the PP1 EB are also low
 - Max stress ~106MPa which is ~50% or less of yield stress at -55°C (depends on SSSL grade)

Modified constraints 1

PEEK sliding contact constraints 4.5mm diameter holes, +/- 250um movement

Two edge sliding contact to constrain the Z movement of the dogleg

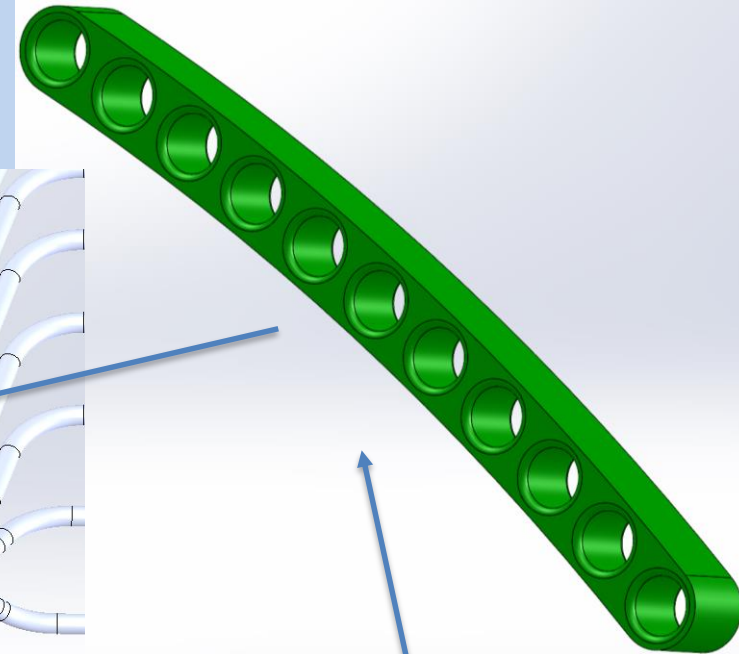
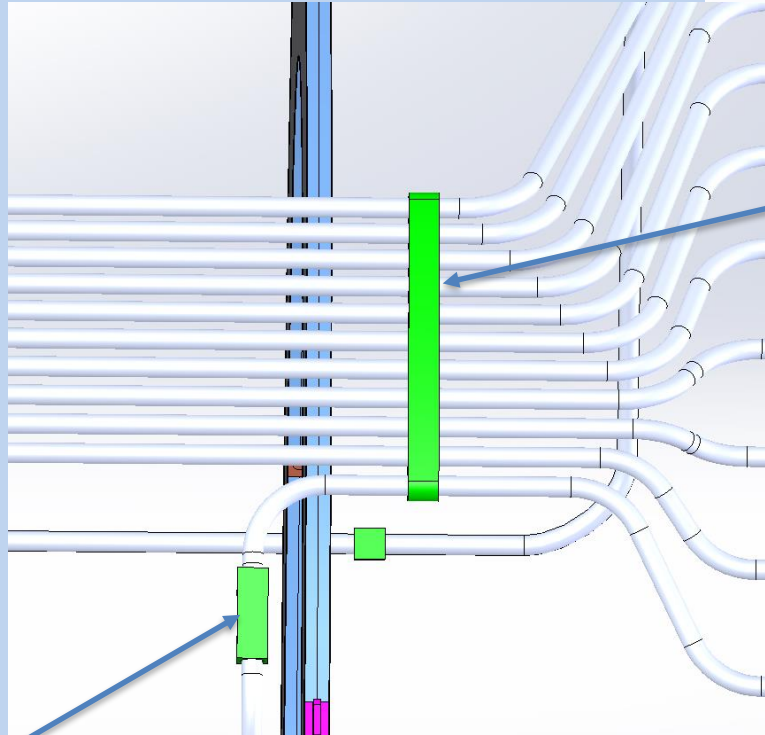
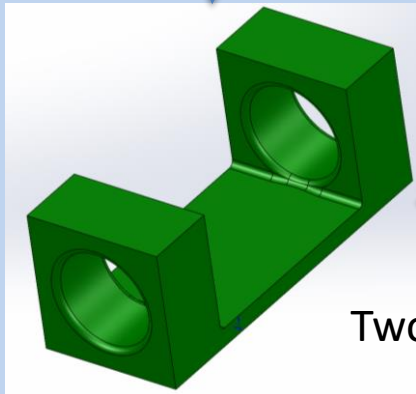


Multiple line constraint used on outlet lines

Modified constraints 2

PEEK sliding contact constraints

Two edge sliding contact to constrain the Z movement of the dogleg



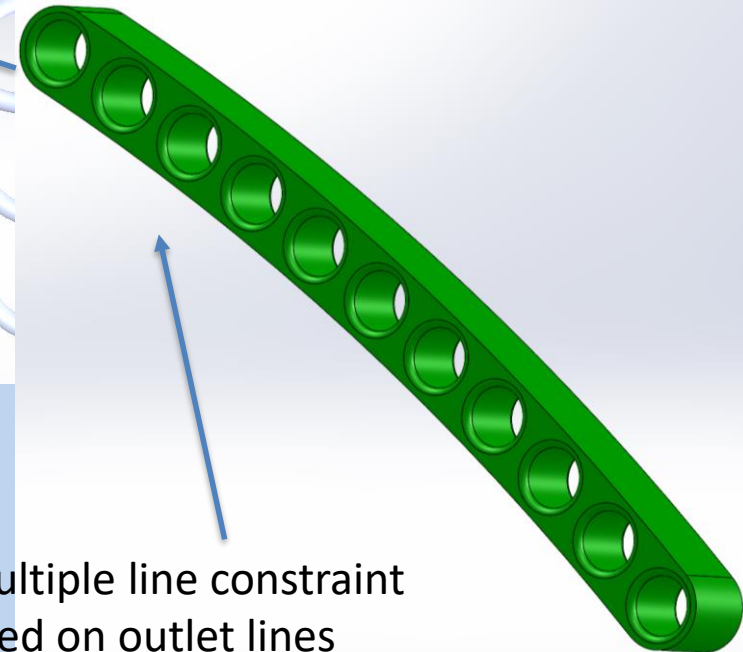
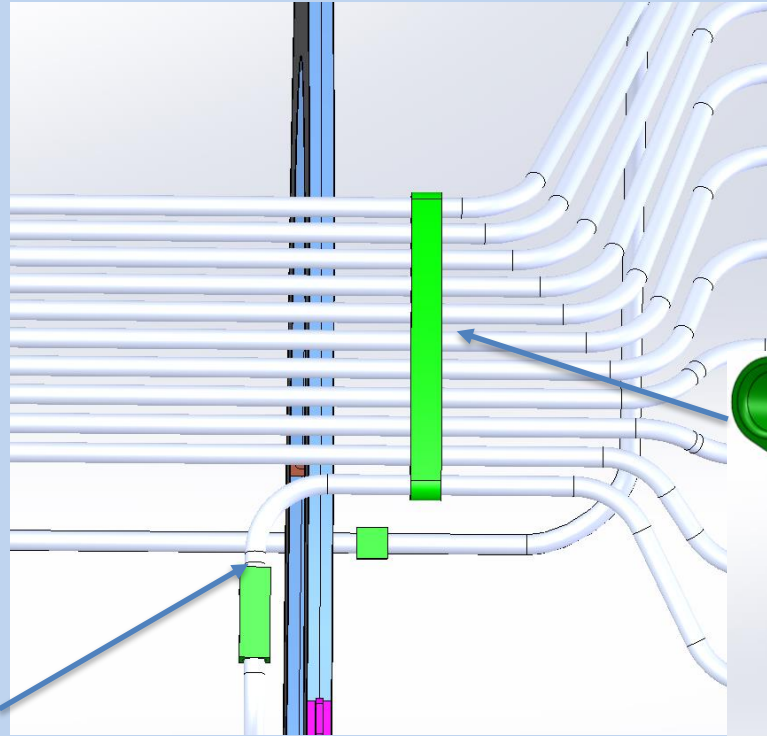
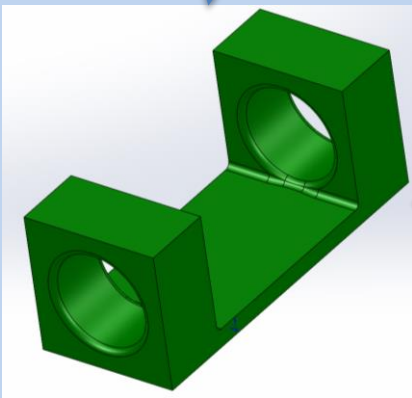
Multiple line constraint used on outlet lines 4.5mm diameter holes

Two edge contact has 4.2mm diameter holes to restrict z-movement

Modified constraints 3

PEEK sliding contact constraints circular holes replaced by ovals 4.2mm minor axis 4.5mm major axis

Two edge sliding contact to constrain the Z movement of the dogleg

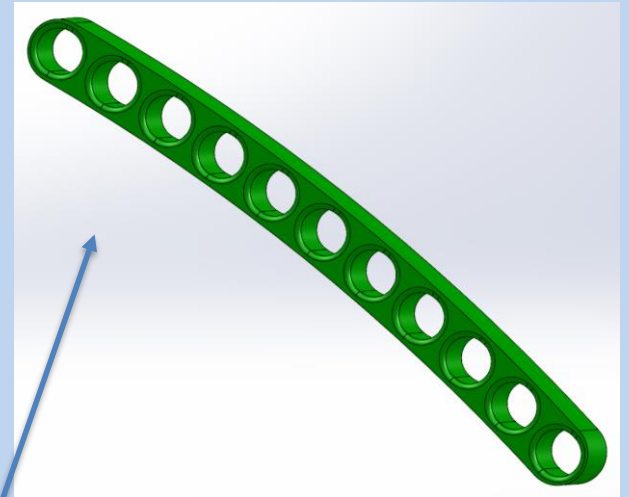
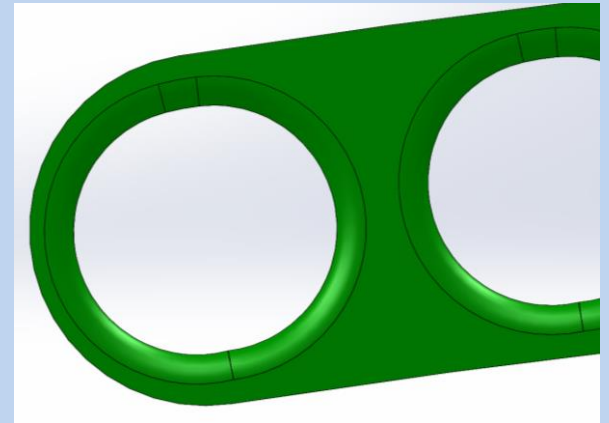
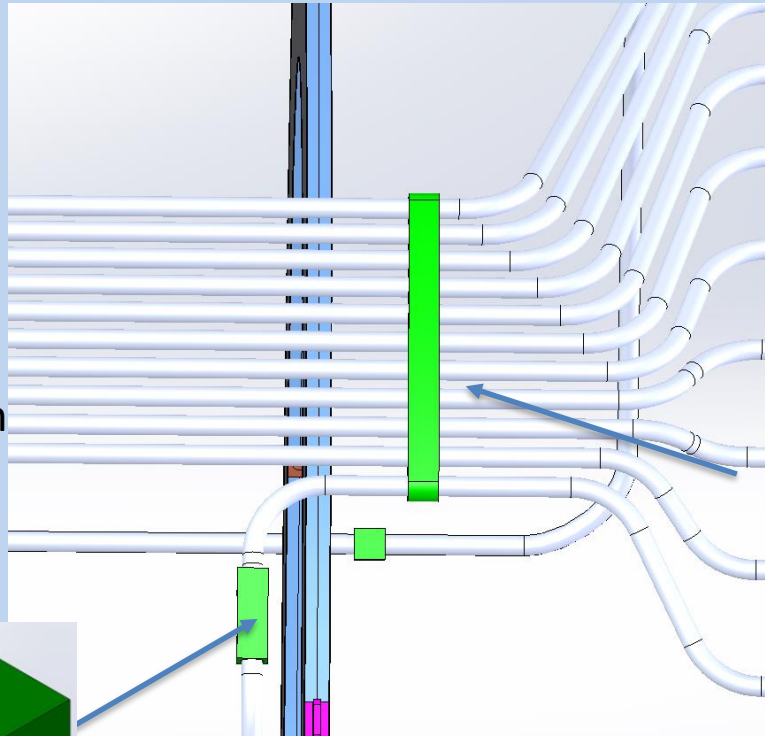


Multiple line constraint used on outlet lines

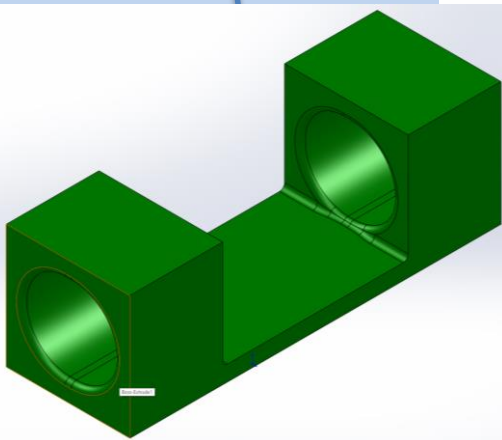


Modified constraints 4

PEEK sliding contact constraints circular holes replaced by slots

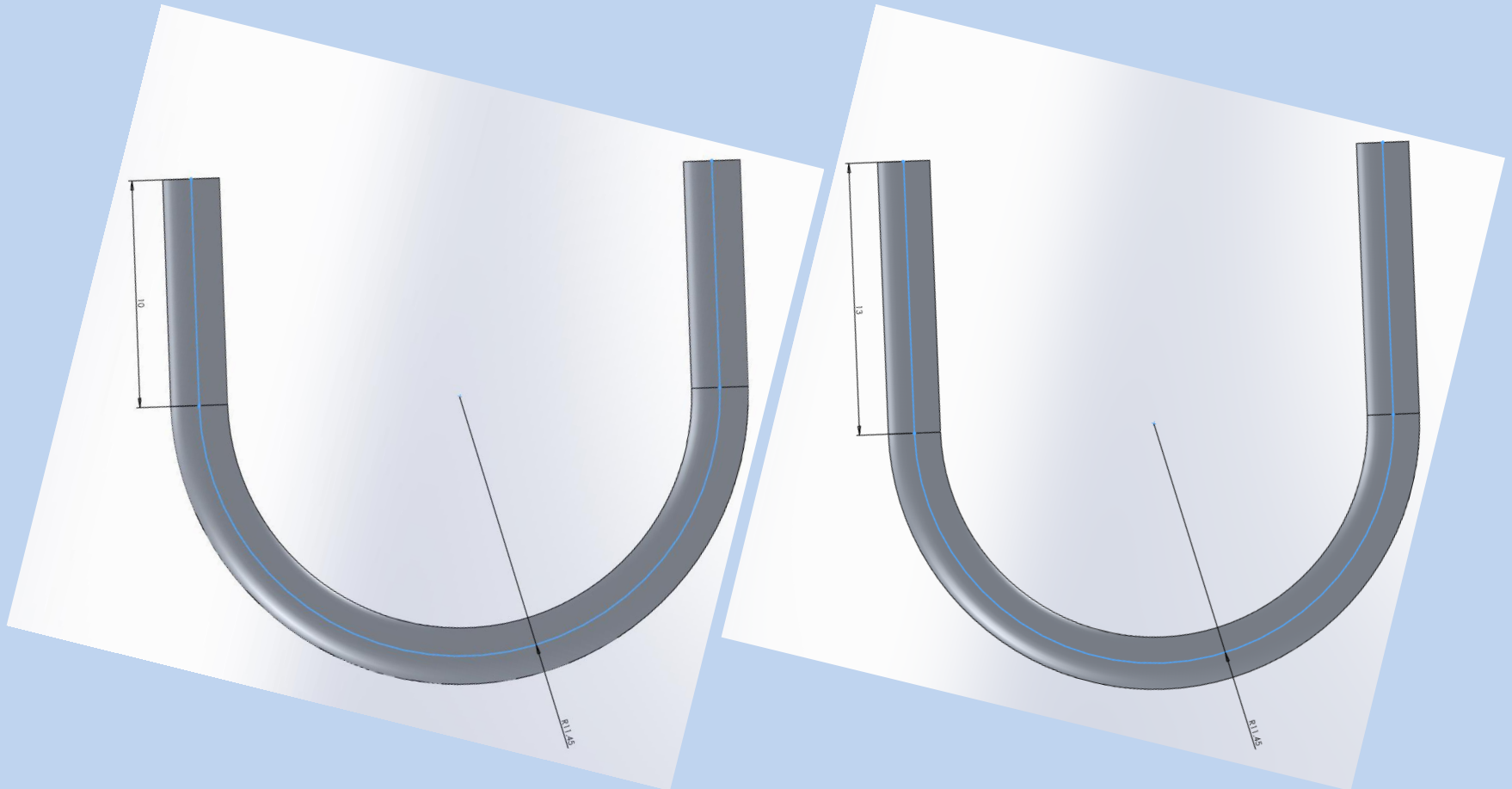


Two edge sliding
contact to constrain
the Z movement of
the dogleg slot 4.2mm
diameter 4.5mm long



Multiple line constraint used on outlet lines,
curved slots follow curvature or comb,
4.2mm diameter 4.5mm long on a radius.

Modified U-bend



Changed the length of the straights on the U-bend from 10mm to 13mm and compared the stress results to modified constraint 4

Comparison of results for modified constraints



Constraint type	Max equiv. stress (MPa)	Z movement (mm)		Y movement (mm)		X movement (mm)	
		+ve	-ve	+ve	-ve	+ve	-ve
Original	177	0.48	0.98	0.46	0.3	0.46	0.65
Mod 1	244	1.1	1.6	0.83	0.38	0.46	1.1
Mod 2	186	0.46	0.8	0.49	0.3	0.31	0.69
Mod 3	224	1.1	1.7	0.68	0.4	0.47	1.0
Mod 4	207	0.81	0.85	0.62	0.31	0.42	0.86
U-bend	195	0.82	0.85	0.65	0.3	0.44	0.86

The change to the U-bend has no real effect on the stress or movement in the pipe runs, so that proposed change seems okay.

Still to run: slot in other direction on dog leg, and making dog leg constraint longer to limit movement

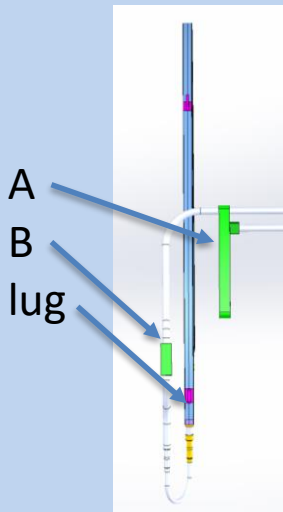
162bar pressure load on LH pipe run

4.5mm diameter constraint

Reaction forces on constraints are all low

Measure both pipe constraints at low-z ring, middle ring and high-z ring and on the manifold.

Also looked at reaction force on the low Z ring lug



constraint	X-force(N)	y-force(N)	z-force(N)	Combined(N)	Combined Moment (Nm)
A1	21.95	9.48	0.00	23.91	0.13
B1	3.16	-9.72	-0.55	10.24	0.08
A2	21.90	5.61	0.00	22.61	0.04
B2	2.29	-8.68	-9.69	13.21	0.06
A3	23.67	0.11	0.00	23.67	0.15
B3	2.18	-6.83	-11.94	13.93	0.08
Lug	-0.23	-5.50	-1.70	5.76	0.07

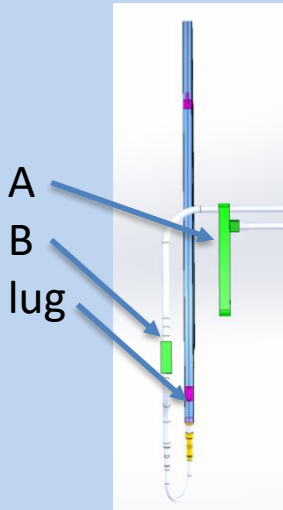
162bar pressure load on LH pipe run slotted constraints



Reaction forces on constraints are all low

Measure both pipe constraints at low-z ring, middle ring and high-z ring and on the manifold.

Also looked at reaction force on the low Z ring lug



constraint	X-force(N)	y-force(N)	z-force(N)	Combined(N)	Combined Moment (Nm)
A1	24.80	9.28	1.61	26.53	0.20
B1	2.09	-11.50	-4.00	12.35	0.07
A2	22.78	7.34	0.95	23.95	0.05
B2	3.02	-10.59	-12.52	16.67	0.08
A3	23.23	3.48	6.19	24.29	0.19
B3	1.73	-7.81	-12.26	14.64	0.12
Lug	-1.44	-3.46	-0.78	3.83	0.04



Summary 2

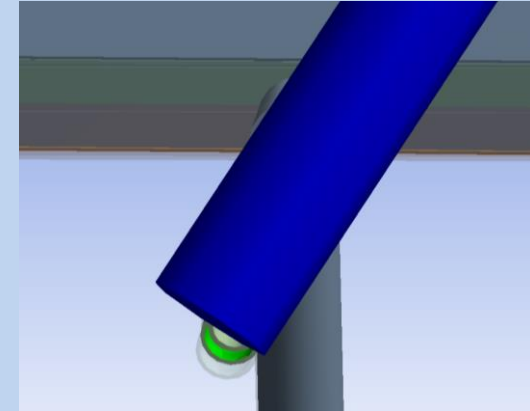
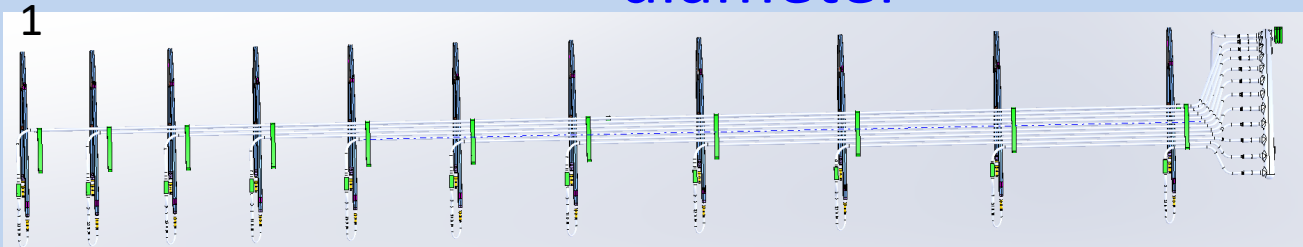
- Changing the constraints on the pipes increases the stress in the U-bend
 - Small change to the reaction loads but no real reduction
- Changing the length of the straights on the U-bend has very little effect
 - Minor improvement in the U-bend stress
 - Small increase in the reaction forces, but still very low
- Need to work on realistic way to constrain pipes that doesn't allow too much movement.
 - Current design requires too much precision?
- Two load cases still to run
 - Change slot direction
 - Change length of dogleg constraint



University
of Glasgow

Experimental
Particle Physics

Forces on ring Ebs: constraints 4.2mm diameter

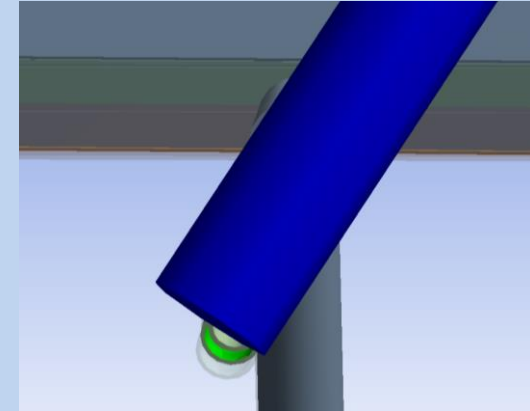
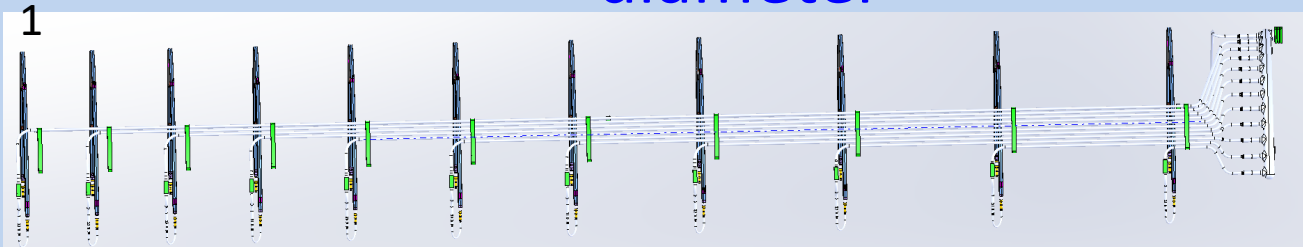


Measured at the end of the EB assembly

Ring no	Load	X (N)	Y (N)	Z (N)	Total (N)
1	1	27.89	-2.30	1.06	28.00
	2	1.22	0.63	1.02	1.71
	3	-0.55	0.69	0.88	1.25
2	1	27.97	-2.33	1.08	28.09
	2	1.09	0.66	1.02	1.63
	3	-0.49	0.61	0.84	1.15
3	1	28.03	-2.36	1.10	28.15
	2	1.14	0.64	0.96	1.62
	3	-0.46	0.59	0.80	1.09
4	1	28.02	-2.36	1.12	28.14
	2	1.14	0.63	0.93	1.60
	3	-0.50	0.61	0.79	1.12
5	1	28.27	-2.43	1.10	28.39
	2	1.24	0.59	0.88	1.63
	3	-0.47	0.59	0.78	1.08
6	1	28.33	-2.53	1.02	28.47
	2	1.30	0.56	0.85	1.65
	3	-0.41	0.54	0.73	1.00

Ring no	Load	X (N)	Y (N)	Z (N)	Total (N)
7	1	28.54	-2.82	0.83	28.69
	2	1.42	0.48	0.72	1.66
	3	-0.19	0.17	0.57	0.63
8	1	28.81	-3.09	0.67	28.98
	2	1.63	0.42	0.50	1.76
	3	0.04	0.14	0.29	0.32
9	1	29.09	-3.18	0.58	29.27
	2	1.75	0.40	0.50	1.86
	3	0.24	-0.14	0.05	0.29
10	1	28.99	-3.17	0.91	29.17
	2	2.20	0.17	0.15	2.21
	3	-0.01	0.27	-0.02	0.27
11	1	29.34	-3.48	1.29	29.57
	2	2.59	-0.12	-0.25	2.60
	3	0.32	0.06	-0.66	0.73

Forces on ring Ebs:constraints 4.5mm diameter



Measured at the end of the EB assembly

Ring noC	Load	X (N)	Y (N)	Z (N)	Total (N)
1	1	26.12	0.47	3.34	26.33
	2	1.14	1.37	0.89	1.99
	3	-0.43	0.63	0.73	1.06
2	1	26.31	0.29	3.19	26.50
	2	0.97	1.35	0.85	1.87
	3	-0.42	0.57	0.68	0.98
3	1	26.38	0.14	3.01	26.55
	2	0.75	1.01	0.87	1.53
	3	-0.40	0.51	0.66	0.92
4	1	26.40	-0.01	2.82	26.55
	2	0.62	0.89	0.83	1.36
	3	-0.42	0.72	0.69	1.08
5	1	26.65	-0.38	2.56	26.77
	2	0.70	0.83	0.73	1.31
	3	-0.17	0.61	0.57	0.86
6	1	28.33	-2.53	1.02	28.47
	2	1.30	0.56	0.85	1.65
	3	-0.41	0.54	0.73	1.00

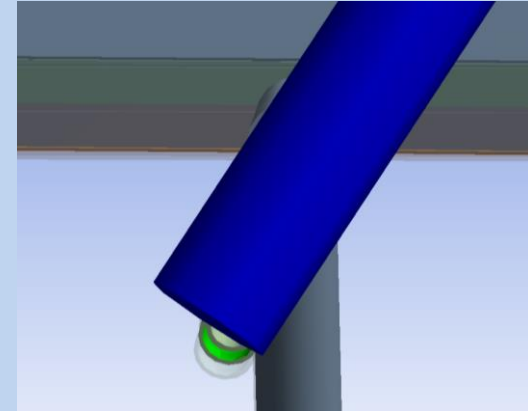
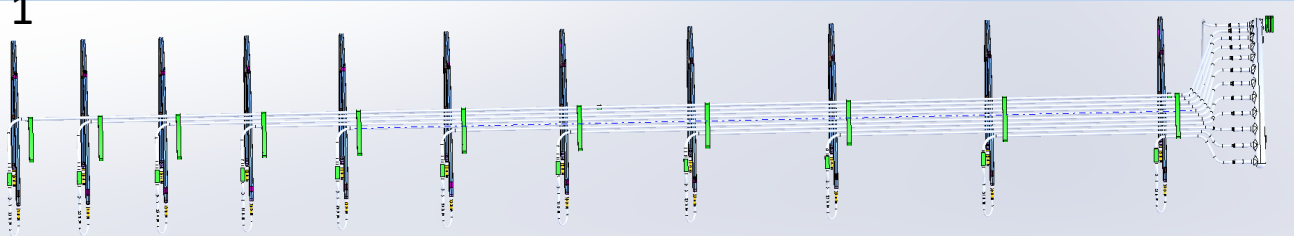
Ring no	Load	X (N)	Y (N)	Z (N)	Total (N)
7	1	26.76	-0.74	2.29	26.87
	2	0.77	0.76	0.67	1.27
	3	-0.15	0.52	0.39	0.67
8	1	27.14	-1.05	1.89	27.22
	2	0.89	0.72	0.67	1.33
	3	-0.17	0.45	0.37	0.61
9	1	27.60	-1.35	1.55	27.68
	2	0.98	0.66	0.66	1.35
	3	-0.27	0.29	0.14	0.42
10	1	27.99	-1.54	1.37	28.07
	2	1.29	0.53	0.70	1.56
	3	-0.07	0.21	0.11	0.25
11	1	27.93	-1.75	1.84	28.04
	2	1.18	0.62	0.58	1.45
	3	-0.04	0.21	0.11	0.24

Forces on ring Ebs:z-line constraints 4.5mm diameter dog leg 4.2mm diameter



1

11

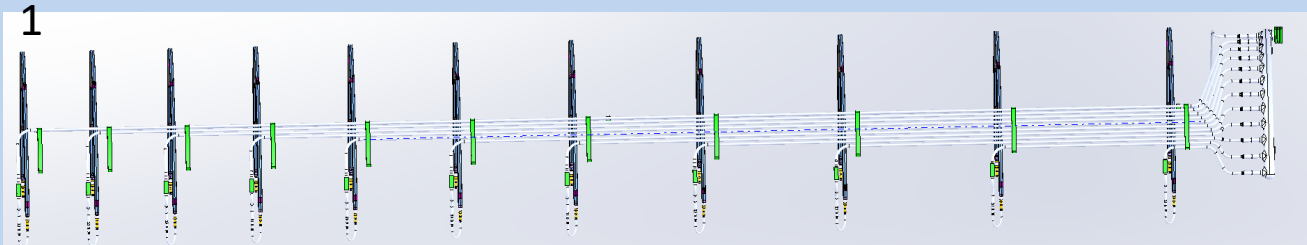


Measured at the end of the EB assembly

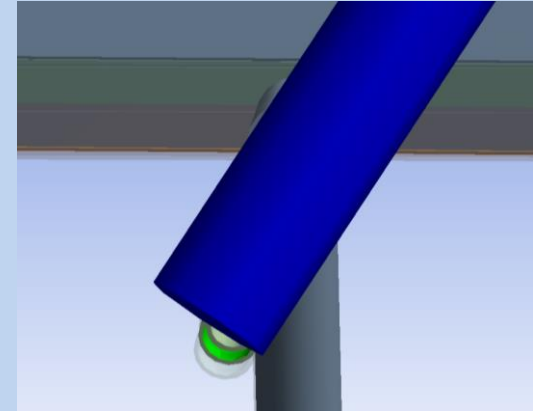
Ring no	Load	X (N)	Y (N)	Z (N)	Total (N)
1	1	28.03	-2.81	1.00	28.19
	2	1.11	0.67	0.90	1.58
	3	-0.07	0.36	0.68	0.77
2	1	28.10	-2.86	1.04	28.27
	2	0.89	0.94	0.89	1.57
	3	0.10	0.66	0.65	0.93
3	1	27.57	-2.36	0.88	27.69
	2	1.06	0.71	0.77	1.49
	3	-0.09	0.37	0.63	0.74
4	1	28.09	-2.86	1.07	28.25
	2	1.06	0.70	0.86	1.53
	3	-0.02	0.26	0.62	0.67
5	1	28.24	-2.97	1.05	28.42
	2	1.08	0.67	0.83	1.51
	3	0.02	0.22	0.61	0.65
6	1	28.24	-3.03	0.98	28.42
	2	1.05	0.66	0.83	1.49
	3	0.03	0.19	0.59	0.62

Ring no	Load	X (N)	Y (N)	Z (N)	Total (N)
7	1	28.34	-3.14	0.78	28.53
	2	1.03	0.63	0.68	1.39
	3	0.04	0.17	0.50	0.53
8	1	28.64	-3.21	0.38	28.82
	2	0.84	0.79	0.67	1.33
	3	0.07	0.16	0.35	0.39
9	1	28.94	-3.32	0.18	29.13
	2	1.06	0.64	0.45	1.32
	3	-0.09	0.44	0.36	0.58
10	1	28.73	-2.84	0.45	28.88
	2	1.45	0.45	0.01	1.52
	3	-0.31	0.50	-0.09	0.60
11	1	28.77	-3.42	1.14	29.00
	2	1.55	0.43	-0.18	1.62
	3	-0.11	0.29	-0.64	0.71

Forces on ring Ebs: slotted constraints



Measured at the end of the EB assembly



Ring no	Load	X (N)	Y (N)	Z (N)	Total (N)
1	1	26.62	-1.33	2.18	26.74
	2	0.76	1.09	0.77	1.53
	3	-0.51	0.47	0.64	0.95
2	1	26.69	-1.37	2.32	26.83
	2	0.63	1.03	0.76	1.43
	3	-0.34	0.34	0.56	0.74
3	1	27.52	-1.51	1.44	27.59
	2	0.59	0.89	0.67	1.26
	3	-0.47	0.42	0.52	0.82
4	1	27.04	-1.36	2.06	27.15
	2	0.67	0.79	0.56	1.18
	3	-0.38	0.43	0.49	0.75
5	1	27.59	-1.47	1.63	27.68
	2	0.63	0.88	0.53	1.21
	3	-0.35	0.36	0.39	0.63
6	1	27.55	-1.49	1.76	27.64
	2	0.66	0.71	0.61	1.14
	3	-0.21	0.27	0.30	0.45

Ring no	Load	X (N)	Y (N)	Z (N)	Total (N)
7	1	27.90	-1.60	1.51	27.99
	2	0.90	0.89	0.63	1.42
	3	-0.26	0.28	0.19	0.43
8	1	28.28	-1.81	1.26	28.37
	2	0.79	0.76	0.58	1.24
	3	-0.47	0.36	0.20	0.62
9	1	28.58	-2.05	1.20	28.68
	2	1.16	0.58	0.56	1.42
	3	-0.14	0.23	0.03	0.27
10	1	28.30	-2.16	1.70	28.43
	2	1.32	0.58	0.59	1.56
	3	-0.09	0.25	0.07	0.28
11	1	28.09	-2.61	2.28	28.30
	2	1.48	0.58	0.22	1.61
	3	-0.09	0.38	-0.01	0.39