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ATLAS CENTRAL (VI) BEAM PIPE ANALYSIS

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1 Introduction

This study has the objectives of verifying the maximum deflection and stress induced in the central part of ATLAS vacuum beam pipe (called VI in the ATLAS PBS) by the weight of the components installed and of calculating the minimum force required to produce buckling.

The analysis performed has been developed through the following steps:

- First of all the equivalent loads applied at the end of the VI beam pipe were calculated.

- Then a FEA model has been built and solved in order to evaluate deflection, stress and buckling force induced in VI.

2 Loads and Constraints

2.1 Loads

The first step of this analysis was to evaluate the maximum moment applied at the end of VI.

The components whose weight was considered to produce a moment are the stainless steel flange, the ion pump, two stainless steel bellows and the stainless steel tube in the adjacent VA section.

The axial compression due to the reaction to the thermal expansion from the bellows was also taken into account; this force gives also an additional moment because of the possible misalignment of the stainless steel tube. A maximum value of 7 mm of misalignment was introduced in the calculations (worst case).

Table 1. Equivalent moments induced by the weight of the components along the stainless steel part (VA) of the beam pipe

Component	**Weight [Kg]**	**Distance from point B [mm]**	**Moment in B [Nm]**
Stainless steel flange	0.9	7	0.062
Ion pump	2.0+2.0	121	4.75
Bellows 1	0.450	267	1.18
Bellows 2	0.450	583	2.58
Stainless steel tube	0.2	394.5	0.774

The following table gives a resume of the loads applied in point B:

Table 2. Loads in point B.

AXIAL COMPRESSION [N]	330
MOMENT DUE TO MISALIGNMENT [Nm]	2.31
TOTAL MOMENT IN POINT B (worst case) [Nm]	11.65

2.2 Constraints

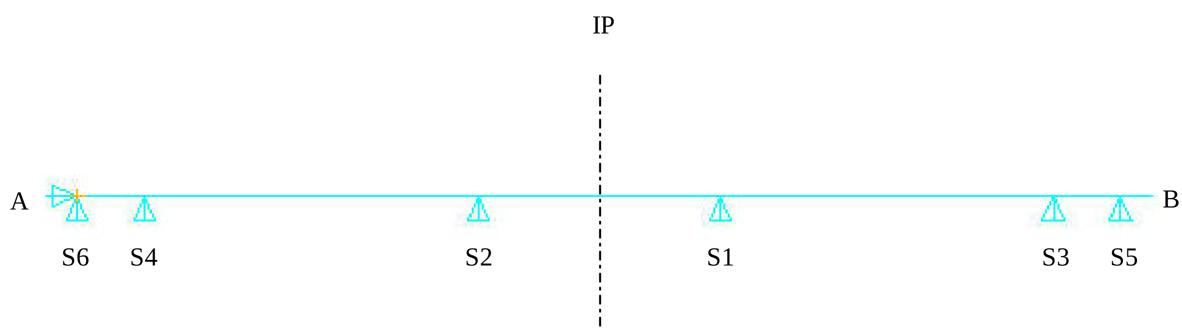
The VI beam pipe is supported by 6 supports.
Their position from point IP is summarised in table 3.

Table 3. Position of the supports.

Support	**Distance from IP**	**Kind of constraint**
1	800	No lateral [y] movement is allowed
2	-800	No lateral [y] movement is allowed
3	3000	No lateral [y] movement is allowed
4	-3000	No lateral [y] movement is allowed
5	3445	No lateral [y] movement is allowed
6	-3445	No movements are allowed

To take in account also a maximum offset of 2 mm of the tile calorimeter, support number 5 is considered displaced by –2 mm in vertical [y] direction.

Figure 1. Position of the supports



3 Finite element analysis

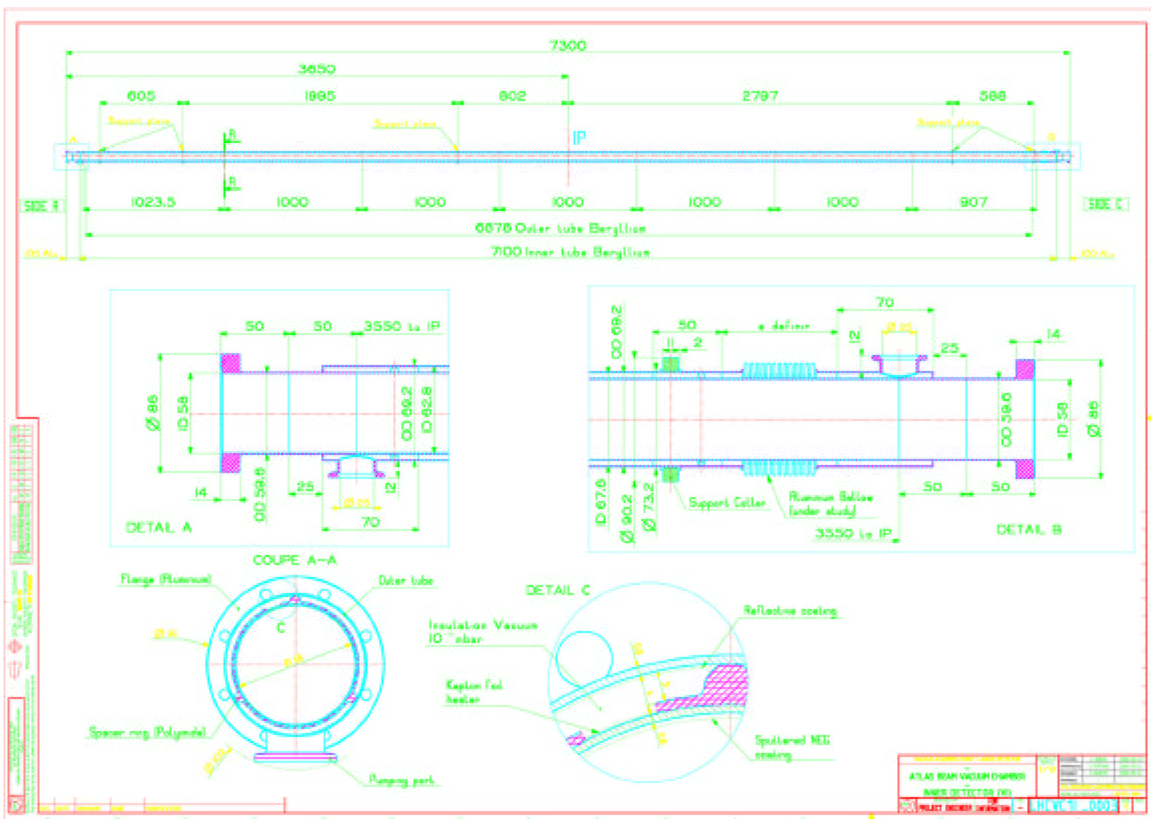
3.1 Geometrical Layout

The dimensions of beryllium and aluminum sections are listed in table 4:

Table 4. Dimensions of the beam pipe

Part	**Length [mm]**	**External Diameter [mm]**	**Internal Diameter [mm]**
Aluminum 1	100.0	60.0	58.0
Beryllium	7100.0	59.6	58.0
Aluminum 2	100.0	60.0	58.0

Figure 2. Geometrical Layout of the beryllium and aluminium part of the beam pipe



3.2 Material Properties

The following table gives a resume of beryllium and aluminium material properties values used in the calculations.

Table 5. Material properties

Material	**Young's Modulus [GPa]**	**Poisson's ratio**	**Yield stress at baked-out temperature [250^{0}C] [MPa]**
Aluminum 2219 T6	72	0.33	200
Beryllium S200	303.3	0.03	240

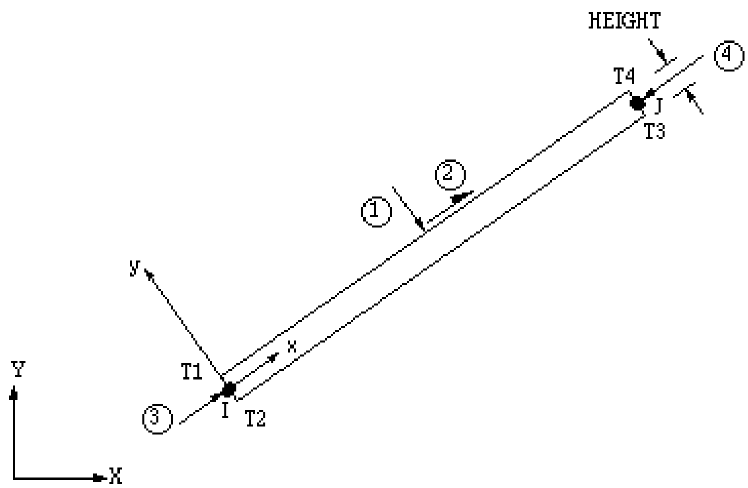
3.3 Element Type

The element type chosen for this analysis was BEAM 3.

The cross sectional area and the thickness are introduced as real constants in the calculations.

BEAM3 is a uniaxial element with tension, compression, and bending capabilities. The element is defined by two nodes, the cross-sectional area, the area moment of inertia, the height, and the material properties. It has three degrees of freedom at each node: translations in the nodal x and y directions and rotation about the nodal z-axis.

Figure 3. BEAM 3

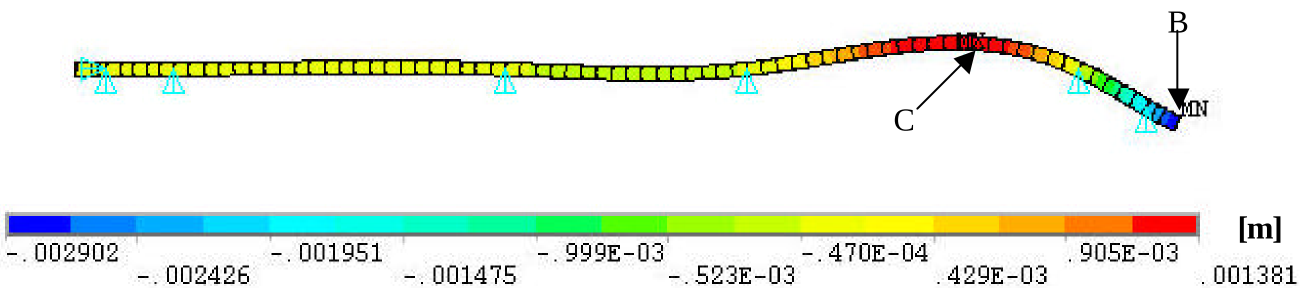


3.4 Results: deformations, Von Mises equivalent stress and buckling force

The maximum values of the deformation are reached in two points:

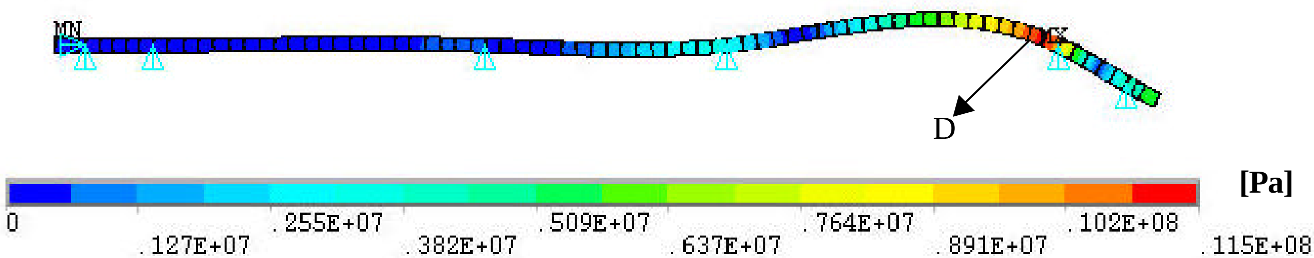
- Point B, where the maximum value reached is of –2.902 mm (taking into account the imposed displacement on the last support).
- Point C, maximum value 1.381 mm.

Figure4. Deflections of the beam pipe



The maximum Von Mises stress value is reached in point D: 11.5 MPa, well below the beryllium yield stress limit at baked-out temperature of 240 MPa.

Figure5. Von Mises stress distribution



The critical axial buckling load is of 19157 N, which compared with the 330 N expected from table 2 gives a large margin, even if the axial compression force would be higher than the imposed one.

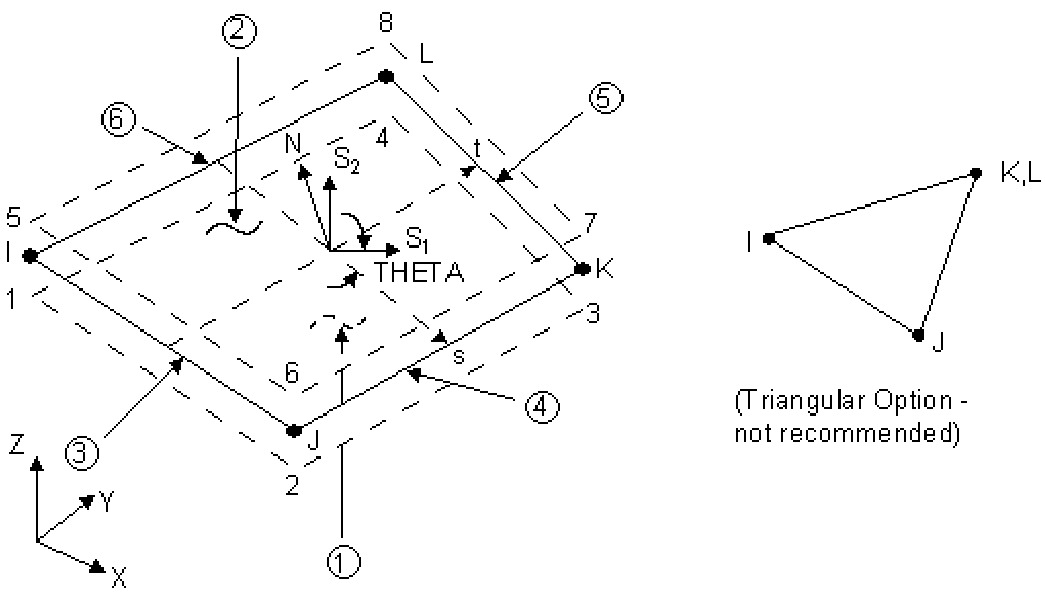
Table 6. Results of FEA analysis

Maximum deflection [mm]	**Minimum deflection (offset of 2 mm+deflection) [mm]**	**Maximum stress [MPa]**	**Minimum buckling force [N]**
1.318	2.902	11.5	19157

3.5 Buckling under external pressure

A shell model of the beam pipe has been built to study the buckling behaviour of the VI beam pipe under external pressure.
The element type used is SHELL181, a four-noded element with six degrees of freedom at each node, suitable for analysing thin to moderately thick shell structures.

Figure6. SHELL181



Material properties and constraints are the same as used in the beam analysis.
A linear eigenvalue analysis was performed.

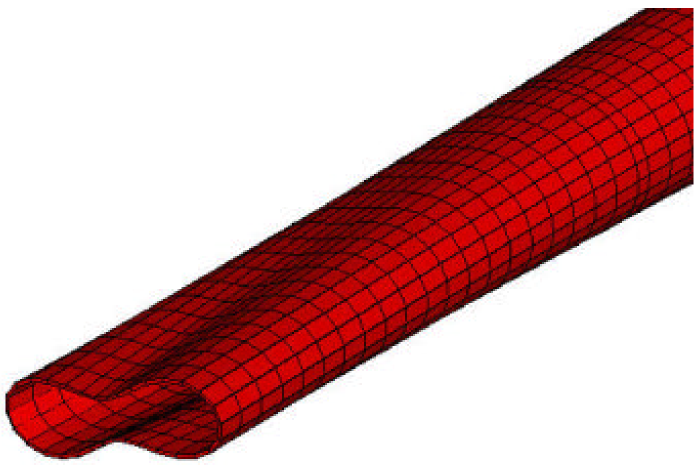
The value of the critical pressure obtained is reported in table 7, together with approximate values of the critical pressure calculated using standard analytical formulas.

Table 7. Critical buckling pressure

Minimum critical buckling pressure for an infinitely long cylindrical shell in Beryllium S200 [bar]	**Minimum critical buckling pressure for an infinitely long cylindrical shell in Aluminum 2219 T6 [bar]**	**Minimum critical buckling pressure - ANSYS linear buckling analysis [bar]**
15.9	8.28	7.85

In figure 7 the deformed shape of the pipe in case of buckling under external pressure is shown.

Figure 7. Deformed shape of the pipe



4 Conclusions

The maximum Von Mises stress value reached, 11.5 MPa is well below the beryllium yield stress limit at baked-out temperature, 240 MPa: an elastic behavior of the pipe should be guaranteed.

The axial load imposed, 330 N, is less than the 2% of the critical axial buckling load calculated, 19157 N.

The critical buckling pressure, corresponding to the value of the lowest buckling mode in FEA analysis, was checked applying analytical formulas for an infinitely long cylindrical shell assuming that the beam pipe is entirely made of either aluminum or beryllium.
That shows clearly that buckling will first occur in the aluminium part of the beam pipe.