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MATEO

MATEO ANTASME

ADVANCED MODELLING TECHNIQUES for AEROSPACE SMEs

DELIVERABLE 9.3 – "IMPLEMENTATION OF THE FEM DATA IN THE SINDA/FLUINT NETWORK SCHEME"

NOMENCLATURE

Variable	*Description*
A [m^2]	Flow area
FK	Pressure drop factor for valve
$\dot{m}$ [kg/s]	Flow rate

Greek

Variable	*Description*
ρ_l	Liquid density
μ	kinematic viscosity

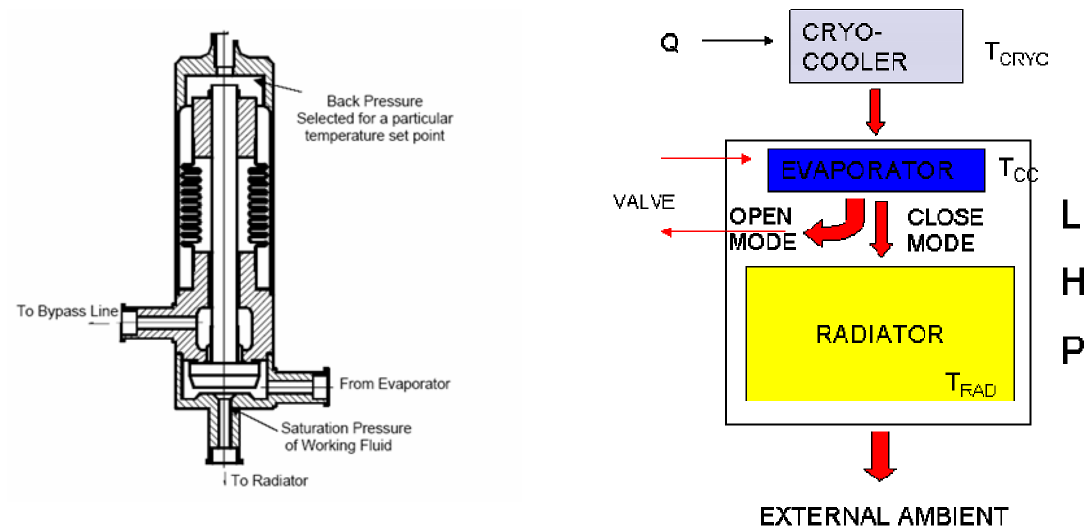
Subscripts

Variable	*Description*
CC	Compensation chamber
CRYO	Cryo-cooler
Rad	Radiative

1 INTRODUCTION

The present deliverable concerns a study on the LHP discussed in Marengo & Zinna [1] During that analysis the LHP working was studied for 21 different orbital conditions. The cryo-cooler connected to the LHP was found to be lower than the minimum allowed value for the most of the cases. In order to avoid extra-operational and transitory failures a recent development defined the design and fabrication of a new propylene LHP with a by-pass valve. The numerical integration of the valve inside the lumped LHP model is introduced here.

The valve stem into a bellows that divides the valve housing in two pressure compartments (Fig. 1.1). The pressure difference between the two compartments acts on the valve stem and initiates its movement into a closed/open position. A compressed gas (Argon) creates the back-pressure on the upper side while the pressure in the other compartment is the saturation pressure of the fluid (Propylene).



(a) **(b)**

Fig. 1.1. Simplified valve design (a) and integration in the LHP scheme (b)

The purpose of the valve is to keep the Cryo-cooler above a fixed minimum operating temperature. During the normal LHP running the power absorbed from the evaporator across the valve (close mode, Fig. 1.1b), but when the power rejected from the satellite is low, the valve separates the evaporator from the radiator (open mode), avoiding the cryocooler reaching icing temperatures. With a wrong valve set point the cryocooler temperature may decrease under the minimum operating temperature causing a dangerous failure of the satellite thermal control.

Because its particular and innovative design, the valve needs a FEM simulation of the thermohydraulics characteristics to be implemented in the SINDA/FLUINT code. The objectives of the FEM work is to characterize the valve by a thermodynamic and fluid-mechanical point of view. The FEM analysis is carried out from EINDHOVEN University and implemented in the SINDA/FLUINT scheme as showed in the following paragraph.

1.1 FEM data integration

Depending on the orbital position, the minimum temperature at the valve inlet can reach a range of possible values. Using these data as boundary conditions, the FEM simulation should investigate the pressure drop and the thermal loss inside the valve both in the recycling and in the through-flow operating mode (open/close valve mode).
The results of this work are summarized in the next graphic (Fig. 1.2).

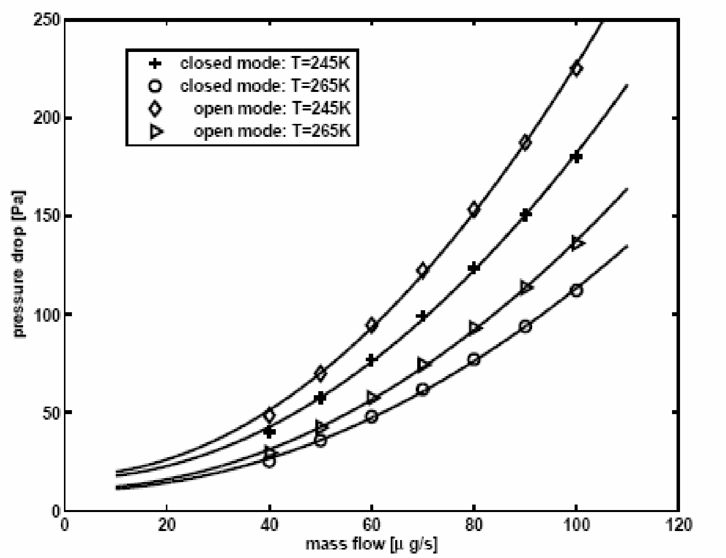


Fig. 1.2. Total pressure drop Δp between inlet and outlet as a function of the mass flow

The dimensional analysis defined by Speetjens & Rindt [3] suggests that the pressure drop scales proportionally with the kinematic viscosity. In the same work they show that the results in Fig. 1.2 could be good approximated by the following equation:

$$\Delta P = \frac{\mu}{\mu_{245}}\left[A_{245}\,\dot{m}^2 + B_{245}\right] \quad \textbf{1.1}$$

Where the coefficient are listed in the next table.

	T=245; closed	T=265; closed	T=245; open	T=265; open
A	0.016576	0.010302	0.021755	0.013172
B	16.2306	10.2695	14.6568	9.0388

Table 1.1 Pressure drop coefficient

By using the coefficient in table 1.1, the equation 1.1 is able to define the fluid pressure drop. Moreover by the considerations explained in Speetjens & Rindt [7] the propylene flows admits simplification to a fully incompressible and isothermal flow.
The steady state results provided by this analysis make the valve a separate object that can be integrated in the lumped code in order to run different orbital conditions. The SINDA/FLUINT scheme is composed by a solid (SINDA) network and a fluid one (FLUINT) [3]. In this scheme the valve is represented by using 3 nodes (Fig. 4.3): two nodes that account for the fluid (blue) and the other for the solid (grey) lines.

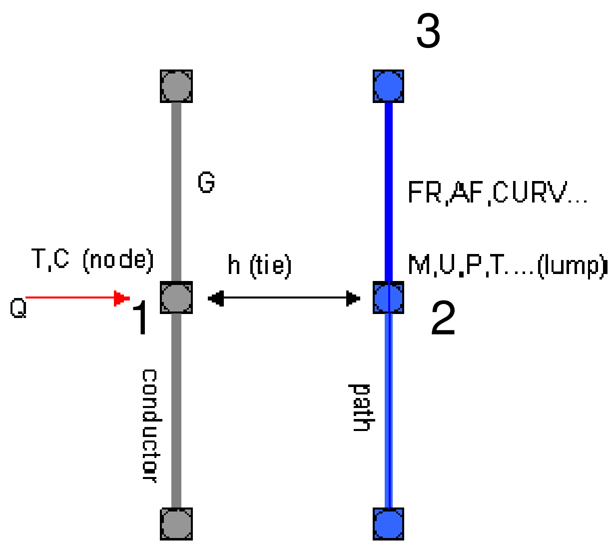


Fig. 1.3. Sinda/Fluint scheme

The path between the fluid nodes (number 2 and 3, Fig. 4.3) accounts for the pressure drop while the connector between node number 1 and 2 represent the heat transfer coefficient. Because the valve is considered isothermal, the latter is negligible while the connector between node 2 and 3 is modelled in FLUINT by an ad-hoc device able to simulate a valve:

$$\Delta P = \frac{FK}{2 \cdot \rho_l} \left(\frac{\dot{m}}{A} \right)^2 \quad \mathbf{1.2}$$

where FK is the pressure drop factor for the valve, A is the flow area and ρ_l is the liquid density. The FK factor can be easily implemented by inspection of the equation (1.1) while the additional pressure drop represented by the B coefficient is added to the path downstream the valve. Finally a combined lumped/distributed simulation can fix the operating transient mode of the valve. The results of this integration are shown in the next paragraph.

1.2 Results

This paragraph shows the results of the integrated FEM-SINDA analysis. In the coldest environment the cryocooler temperature might be below its required minimum value of 263K, therefore in such cases, the bypass valve must be working to maintain the cryocooler above the minimum allowed temperature. The boundary conditions implemented in this work concerns with the worst cold case: beta angle equal to +75 in the coldest environment and minimum power (61W). Moreover the nominal mode is considered consisting of two LHP running together (one of them for redundancy reasons), hence every LHP transports 31.5 W. Two different cases are run with 1 set point and 2 set point respectively.
In the first case one set point is fixed, corresponding to the minimum temperature allowed in the cryo-cooler (263K): when the cryo temperature descends under 263K the valve is open and the vapour goes back to the compensation chamber, otherwise the valve is closed. The moving of the piston inside the valve is considered instantaneous.

The results about the temperatures are shown in the next picture for the cryo (T_{cryo}), the compensation chamber (T_{CC}) and the radiator (T_{RAD} that is the averaged nodes value). The Fig. 4 and 5 show a detail of the cryo and compensation chamber temperature.

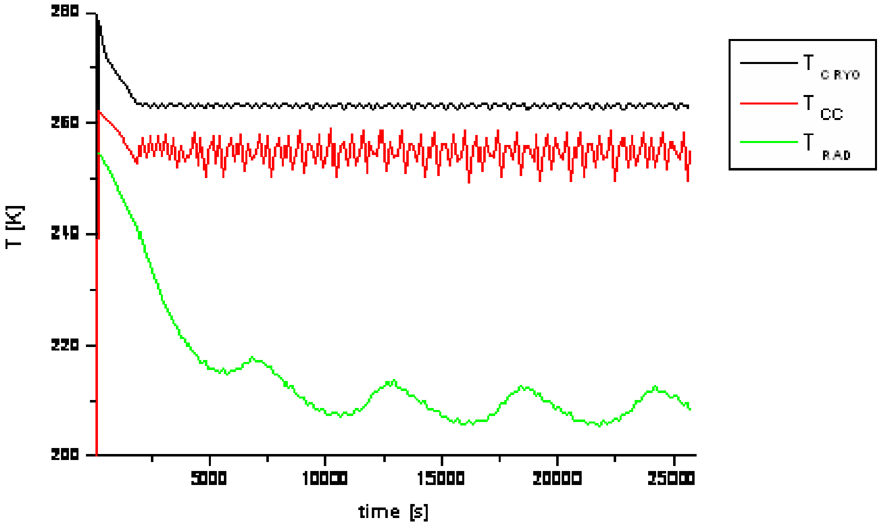


Fig. 1.4. Cryo, compensation chamber and radiator temperatures during the transient, 1 set point

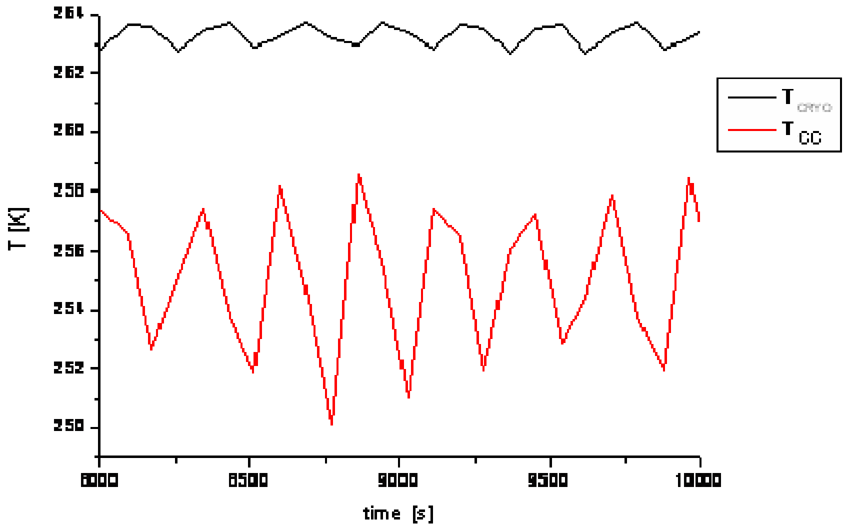


Fig. 1.5. Cryo and compensation chamber temperatures during the transient, 1 set point

The cryo temperature shows an oscillation between 262.7K and 263.7K. After that the cryo reaches 263K the valve is open and the T_{CC} temperature increases instantaneously. The cryo reacts very quickly to the increase of T_{CC} and so it is decreased just a few tenths of K (up to 262.7K) under the minimum 263K value.

In the 1 set point case the piston is considered to react instantaneously to the pressure difference between the argon and the propylene. It is possible to check if this hypothesis is reliably by simple considerations. The piston diameter is about 5mm and its mass is lower

than the overall valve mass (80g). Using these data we can estimate that the piston moves through 1 mm (that is the distance between the open and the close position) in less than 1 second if the pressure difference is about 0.2 Pa. Hence, considering such very low valve inertia, the piston moves almost instantaneously with respect to the flow charatistic times and 1 set point should be considered.
Since the geometric details of the valve are not well known (for example there is still a possible alternative design with a particular spring), to show a different possible setup a simulation of the LHP behaviour with two set points is considered: when the cryo temperature is under the critical 263K value the valve is open and it is closed when it over the 265K. In the range between 263K and 265K both the two paths are open: the SINDA/FLUINT model is able to calculate, depending on the upstream conditions and on the pressure drop, which part of the flow rate goes to the radiator and which back to the compensation chamber.

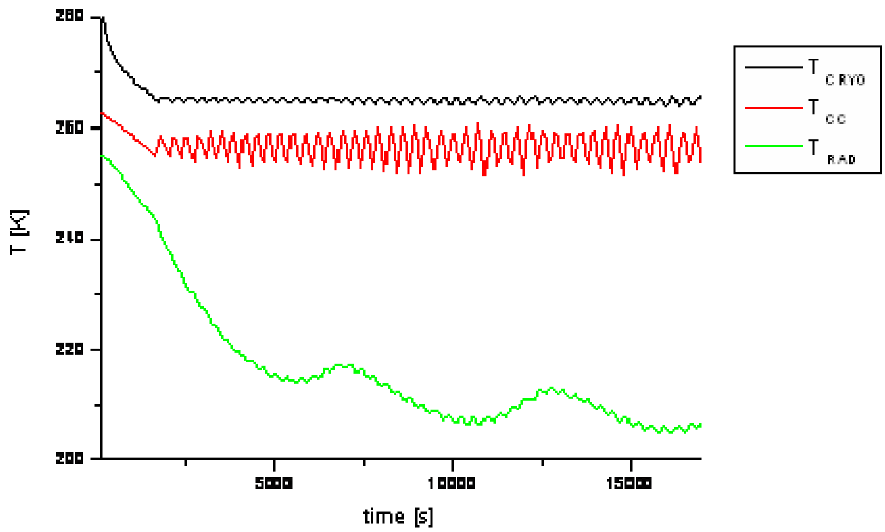


Fig. 1.6. Cryo, compensation chamber and radiator temperatures during the transient, 2 set point

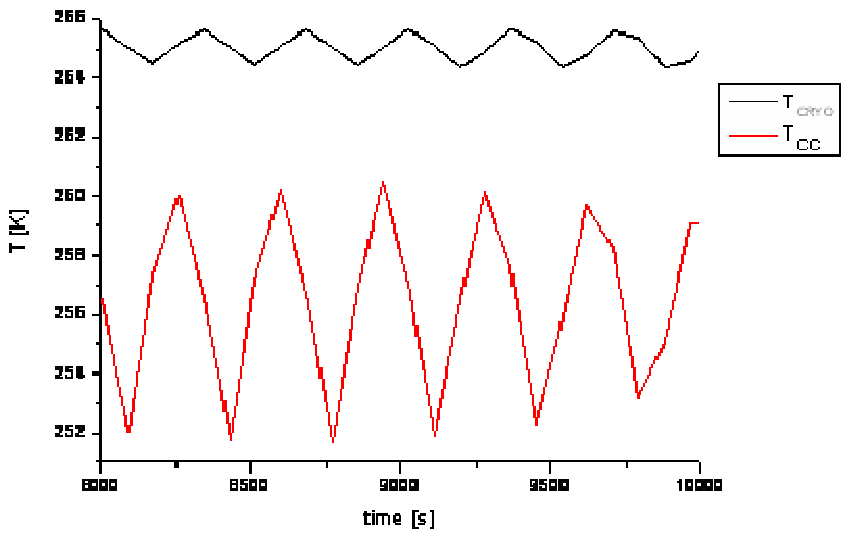


Fig. 1.7. Cryo and compensation chamber temperatures during the transient, 1 set point

Even in this case the model reacts very quickly to the open mode. Even if a part of the flow rate goes to the radiator, the part that flows back through the valve raises the compensation chamber temperature and consequently the cryo temperature. The oscillation is set two degree more than the 1 set point case. Finally, it is possible to see that the oscillations are very slow during the transient preventing the valve from damaging. In fact, the switch between the open and the close mode happens in the first case every 500 s, and in the second case every 700s.

REFERENCE

1. Zinna S. & Marengo M. 2006 Simulation of the LHP in orbital conditions. *INTERREG IIICMATEO-ANTASME Deliverable 8.1.*
2. C&R technologies, SINDA/FLUINT user's manual. March 2004, version 4.6
3. Speetjens M. & Rindt, C. 2006 Analytical model for the bypass valve. *INTERREG IIIC MATEO-ANTASME Deliverable 9.2.*