1. Introduction

For aerospace applications, U-type pulse tube cryocooler (UPTC) can improve the temperature uniformity and structural stability of the cold end which are very meaningful especially for the bay cooling platform. Nevertheless, the influence of the cold end connecting tube on the performance of the UPTC is inevitable. Previous researches put down the performance deterioration of the UPTC to the flow resistance of the cold end connecting tube. In this study, a simplified model of the cold end of the UPTC is developed based on Lagrangian viewpoint. With this model, the periodical thermodynamic processes of the gas parcels flowing through the cold end of the UPTC are obtained. In this way, the influence of the cold end connecting tube is analysed and quantified with the thermodynamic properties of the gas parcels.

2. The model of the cold end of the UPTC

The simplified model of the the UPTC is displayed in figure 1. The time point \( t_0 \) is chosen as the beginning time of the calculation. According to the position at the beginning time, at the gas involved in this model includes two parts as shown in figure 1. The fluctuation calculation is to mirror the thermodynamic processes of these gas parcels during a cycle.

\[ p = p_a + p_b \sin(\omega t) \]
\[ h = h_a + h_b \sin(\omega t + \phi_a) \]
\[ c = c_a + c_b \sin(\omega t + \phi_c) \]

The first half cycle is divided into \( N \) equal time periods. The gas in part 1 flowing through CHEX1 from \( t_0 \) to \( t_1 \) is defined as \( C_1 \). The gas in part 2 flowing through CHEX2 from \( t_2 \) to \( t_3 \) is defined as \( C_2 \). Therefore, the mass of the \( C_1 \) and \( C_2 \) can be defined by Eq. (5) and the total mass can be obtained by Eq. (6) and Eq. (7). The phase shift between the mass flow and pressure at the two cold end heat exchangers is described by Eq. (8).

\[ M_1 = \int_{t_0}^{t_1} \frac{dM_1}{dt} \]
\[ M_2 = \int_{t_2}^{t_3} \frac{dM_2}{dt} \]

\[ \Delta \theta = \arctan(\frac{\Delta h}{\Delta c}) = \arctan(\frac{\Delta c}{\Delta h}) \]

According to Eq. (6) and Eq. (7), the mass of the gas parcels of different time periods are also sinusoidal. Supposing the gas parcels are at their leftmost position at the time \( t_0 \). If the proper beginning time point \( t_0 \) is chosen, all the gas parcels move towards right from \( t_0 \) to \( t_0 + \frac{\pi}{2} \). And then in the following half cycle, these gas parcels move back to the left. Since \( A \) and \( B \) are positive values, the phase angle at the CHEX2 is bigger than that at the HHX while it is smaller than that in the CHEX1. This result verifies the capacitive of the UPTC and the tube pressure.

3. Results and analysis

As shown in figure 1, whether there is piston gas in the CECT depends on the length of the CECT. Nevertheless, according to our analysis and calculating results, for the most of the applications of the UPTC, the length of the CECT is smaller than the critical length. So, the following researches will focus on CECT within the critical length.

The basic parameters of the UPTC are listed in Table 1. Every research involves only one variable which means the value of the remaining parameters are kept constant at the value listed in table 1.

![Figure 1: The simplified model of the UPTC](image1)

![Figure 2a: Cooling power vs. charge pressure](image2a)

![Figure 2b: Cooling power vs. dynamic pressure amplitude](image2b)

![Figure 3a: Cooling power vs. frequency](image3a)

![Figure 3b: Cooling power vs. phase shift at the hot end of the pulse tube](image3b)

![Figure 4: Cooling power vs. the length of the CECT](image4)

![Figure 5: Cooling power vs. the polytropic compression index](image5)

![Figure 6: Cooling power vs. T_c2](image6)

4. Conclusion

a. The CECT has disadvantageous influences on the performance of the UPTC. The influence becomes more and more serious with the increase of the length of the CECT.

b. The CECT have significant influence on the distribution of the cooling power between the two cold end heat exchangers. With the increase of length of the CECT, more and more cooling power transfers from the CHEX1 to the CHEX2.

c. The heat connection between the gas and the CECT is beneficial for the improvement of the performance of the UPTC. The total cooling power tend to increase with the increase of the value of the temperature difference between the gas and the CECT.

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