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C2Or2C-05: Fluid mechanical response of a pulse tube cryocooler: modelling and experimental validation.

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Earth observation satellites require cryocoolers to cool down their infrared imagers at very low temperatures. Besides having very good thermodynamic performances, satellite cryocoolers are expected to generate as little vibrations as possible. In order to better understand vibration causes between 0 and 500 Hz, the whole cryocooler needs to be modelled. In the literature, two main modelling approaches for pulse tube cryocoolers exist: vibration-oriented models reduce the thermodynamic system to a linear mass-spring-damper system acting on compressor's pistons; and thermodynamically oriented models aimed at understanding and predicting thermodynamic performances.

In this paper, the mechanical behaviour of the thermodynamic system is modelled. Assumptions concerning gas properties and thermodynamic behaviour are made based on SAGE software simulations. A simplified Redlich Kwong equation is used. When necessary, polytropic coefficients were identified using simulation data, as were the time-averaged temperatures. The thermodynamic system is split into volumes, pipes and regenerators: conservation laws in volumes are integrated, dynamic mass and momentum conservation equations in pipes are solved using the method of characteristics and equations in regenerators are solved using a finite difference method. Three fiction laws are used: one for straight pipes (Moody chart), another for wound pipes (White's correlation) and a last one for porous media (Modified Ergun equation). Porosity is measured by weighing. The model is built to respect integral causality and propagation phenomena.

The developed model is validated using experimental data. The simulations highlight the non-linear mechanical behaviour of the thermodynamic system: a sinusoidal motion of the pistons induces a non-sinusoidal pressure in the compression chamber. Among other, first and second harmonics amplitudes are about 3% of fundamental pressure amplitude.

This model can now be integrated into a global cryocooler model to predict compressor's vibrations, power consumption or electrical harmonics. It could also be extended to predict vibrations from the thermodynamic system.

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