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Effect of operating parameters on step piston type pulse tube refrigerator

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The pulse tube refrigerator, lacking moving components at low temperatures, has the advantages of high reliability, long operational lifespan, low cost, and ease of fabrication, and is widely used in refrigeration medical, semiconductor processing, aerospace and other fields. The improvement of pulse tube refrigerator mainly comes from the improvement of phase shifter. In traditional pulse tube refrigerator, the expansion work at the hot end of the pulse tube is dissipated in the form of heat in the phase shifter, which decrease the intrinsic efficiency. The work recovery type pulse tube refrigerator can recover the expansion work at the hot end of pulse tube while shifting the phase of pressure wave and volume flow at the cold end of the pulse tube, thereby enhancing the performance of the pulse tube refrigerator. The work recovery type pulse tube refrigerator is currently a hotspot. The developed work recovery type pulse tube refrigerator, by recovering the expansion work at the hot end of the pulse tube, has achieved the high cooling efficiency. However, while realizing the function of work recovery, it is often necessary to add additional moving parts or additional cold heads, which makes the structure of the pulse tube refrigerator complicated and loses the inherent advantages of simple structure. The step piston type pulse tube refrigerator (SP-PTR) is a novel work recovery type pulse tube refrigerator which only requires one moving part and one cold head to achieve the work recovery function. SP-PTR consists of a step piston linear compressor and a pulse tube cold head, featuring a simple structure and high intrinsic efficiency in the high-temperature region. At present, the preliminary experimental verification has been carried out. However, further research is needed. In this paper, a thermoacoustic model of SP-PTR is established, and the influence of operating parameters such as frequency, refrigeration temperature, piston displacement, and operating pressure on the phase shifting ability, work recovery ability, and refrigeration performance of SP-PTR is studied. An experimental setup for SP-PTR has been developed to verify this model. The thermoacoustic model and experimental results indicate that for SP-PTR, there exists an optimal operating parameter that maximizes the efficiency. In the test range, the input voltage mainly affects the efficiency of the pulse tube cold head, while the frequency and operating pressure affect the efficiency of both the step piston compressor and the pulse tube cold head.

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