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Tandem-type pulse tube refrigerator without reservoir

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ABSTRACT

In this paper, a tandem-type pulse tube refrigerator without a reservoir is discussed and investigated. For its practical application a tandem-type compressor is designed to generate two pulsating pressure waves with opposite phases, simultaneously. A tandem-type pulse tube refrigerator consists of a tandem-type compressor and two identical pulse tube refrigerators. The two identical pulse tube refrigerators share the same heat exchangers and one can be connected with the other by an inertance tube without a reservoir. In this proposed configuration, the mechanical vibration and temperature oscillations in the cold-end heat exchanger can be internally suppressed due to its intrinsic opposite-characteristic operation. To examine the quantitative evaluation of the tandem feature which does not require a reservoir in the pulse tube, an evolutionary approach has been attempted. A general structure of a pulse tube refrigerator is modified into tandem Stirling-type and GM-type machines and the transformed configuration has been simulated for tandem operation. The simulation results clearly demonstrate that a properly designed tandem-type pulse tube refrigerator without a reservoir can function favorably.

1. Introduction

In a pulse tube refrigerator (PTR), the mechanical displacer located in the expansion volume of a Stirling refrigerator is replaced with a pulse tube and a phase controller. Without a moving part at the low temperature region, a PTR has several advantages such as high reliability, relatively low vibration and low cost, which are very attractive to many cryogenic applications [1,2]. An inertance-type PTR (IPTR) uses an inertance tube and a reservoir as a phase controller. It generally consists of a compressor, a regenerator, a pulse tube, heat exchangers, an inertance tube, and a reservoir. An IPTR can be driven by a helium compressor to become a Gifford–McMahon (GM)-type IPTR or by a linear compressor to become a Stirling-type IPTR. The typical compressors make only a single pulsating pressure. If the compressors can be modified for tandem-type operation, the modified compressors will make the simultaneous two pulsating pressures, that have identical peak values but opposite phases. This tandem-type concept creates big advantages for an IPTR and other cryocoolers. For this potential benefit, a tandem-type compressor needs to be connected with two identical IPTRs simultaneously. In a tandem-type IPTR, the vibration and temperature oscillations at the cold-head heat exchanger can be reduced if a tandem-type IPTR utilizes properly the two pulsating pressures of opposite phases. Also, the duty of a regenerator can be reduced because a tandem-type compressor has two identical IPTRs and the required mass flow rate of a regenerator is decreased. It means that the tandem-type concept for an IPTR can be useful for high capacity IPTRs. A reservoir which occupies most of the volume of a normal IPTR can be eliminated in a tandem-type IPTR. One of the IPTRs can be connected to the other identical IPTR with an inertance tube, because one IPTR has the pressure and the mass flow rate of the opposite phase conditions as compared to the other IPTR. Additionally, a tandem-type IPTR can be developed as a recuperative 4 K PTR [3] and a tandem-type operation can be also applied to a pulse tube engine [4].

In this paper, a tandem-type concept is applied to an IPTR. Various configurations of tandem-type IPTRs are developed and we explain how these configurations work properly. Specifically, a suggested tandem-type IPTR can internally reduce the vibration and temperature oscillations of a cold-head heat exchanger and it does not require a reservoir. To confirm the feasibility of the suggested idea, the structure of a normal pulse tube refrigerator is modified to proper tandem-type IPTRs and simulated. Simulation

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results show that a tandem-type IPTR without a reservoir can practically work as designed.

2. Concept of tandem-type IPTR

A tandem-type PTR has a compressor that makes two pulsating pressure waves of opposite phases and it has two PTRs. Fig. 1 shows the schematic diagrams of tandem-type compressors. A helium compressor is connected with a specially designed rotary valve. The rotary valve has a valve seat part and a valve head. The valve seat and the valve head parts are modified to transfer simultaneously a high pressure wave and a low pressure wave to two PTRs. Fig. 1(a) shows the schematic diagram of the specially designed rotary valve and pressures measured at the regenerator inlets of the tandem GM-type PTR [3].

A usual linear compressor has one reciprocating piston that is controlled by a linear motor. By adding a second piston at the other end of the motor shaft, a linear compressor can be modified for a tandem type compressor. Fig. 1(b) shows the schematic diagram of the tandem-type single-acting and double-acting linear compressors. A tandem-type double-acting linear compressor needs a transfer line in order to connect the oscillating flow generated from the left side of a tandem-type double-acting linear compressor to that generated from the right side. To make the physical conditions in two Stirling-type PTRs symmetric, the configuration of the transfer line for the pulsating pressure port II should be identical with that for the pulsating pressure port I. With these simple modifications, conventional compressors can generate two pulsating pressure waves of opposite phases, simultaneously.

Fig. 2 shows the basic configuration of a tandem-type PTR and a phasor diagram. A tandem-type PTR is composed of two identical PTRs. The phase control system in an IPTR consists of an inertance tube and a reservoir. Since this configuration is analogous to a warm expander system, the inertance tube and the reservoir are replaced with a warm expander system [5]. We can assume that one PTR is connected to the other PTR with a tandem-type warm expander as shown in Fig. 2(a). In this hypothetical condition, it is expected that a mass flow rate and a pressure of one PTR should

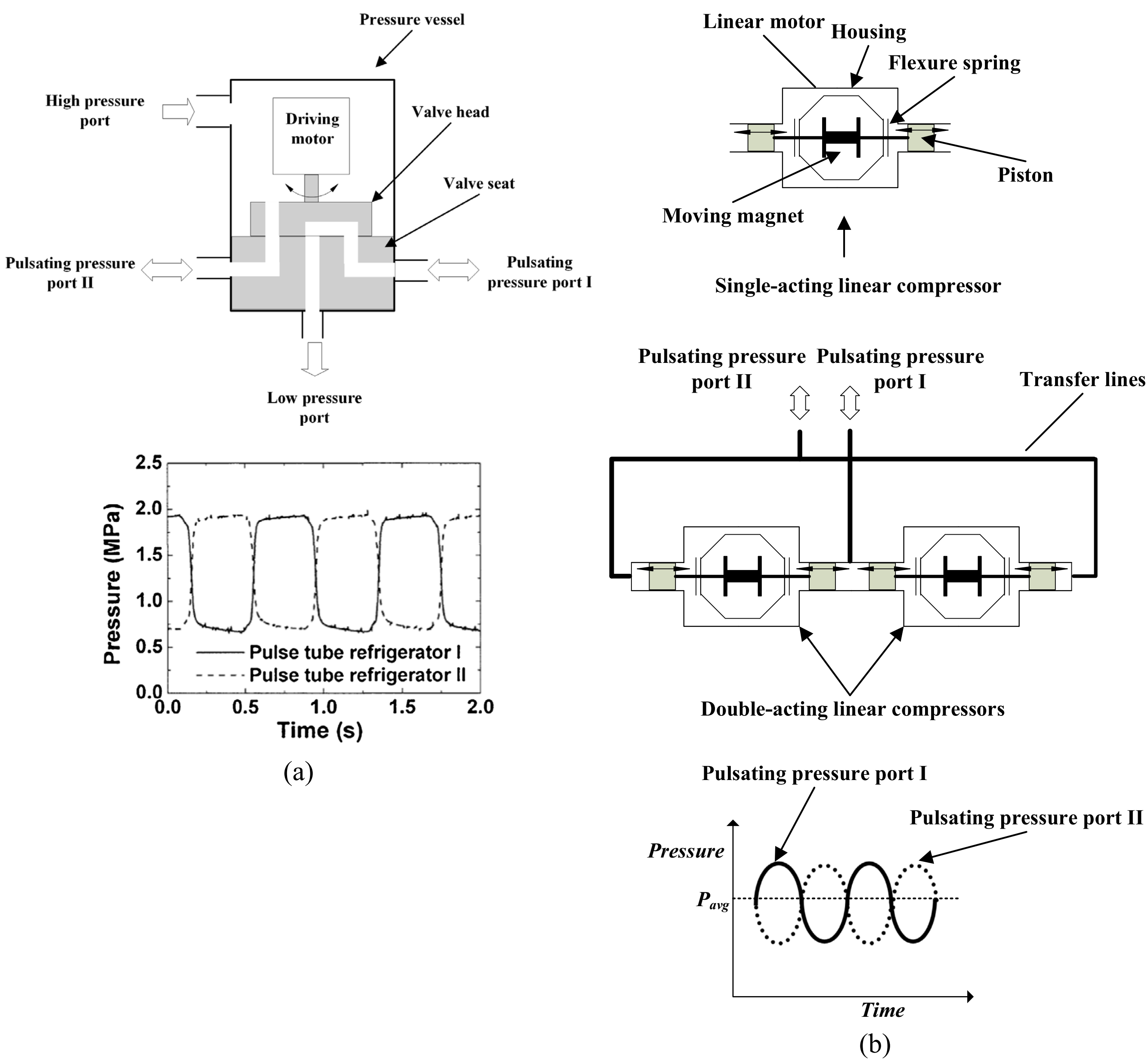

Fig. 1. Schematic diagrams of tandem-type compressors. (a) Rotary valve for helium compressor and pressures measured at regenerator inlets [3], (b) linear compressor.