Low Frequency Linear Compressors for GM and Pulse Tube Cryocoolers

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ABSTRACT

There is a need for efficient, oil-free and long lifetime compressors for low frequency GM and pulse tube cryocoolers. Pressure Wave Systems GmbH is proposing a hydraulic solution to directly generate and feed the pressure wave to the cold head. A second technology demonstrator has been built and tested. A pV-efficiency of near 70% has been demonstrated driving a small dual stage 4K GM cryocooler with an operating frequency of 1Hz and an electrical input power of 1.4kW.

INTRODUCTION

The efficiency of low frequency GM and pulse tube cryocoolers is governed by the efficiency to generate the pressure in the compressor and the efficiency of the rotary valve as well as the design of the cold head, which we will not discuss in this paper.

As scroll capsules have reached their limit at around 50% pV-efficiency, the losses in the rotary valve can be as high as 50%[1]. The loss mechanism is depicted in figure 1.

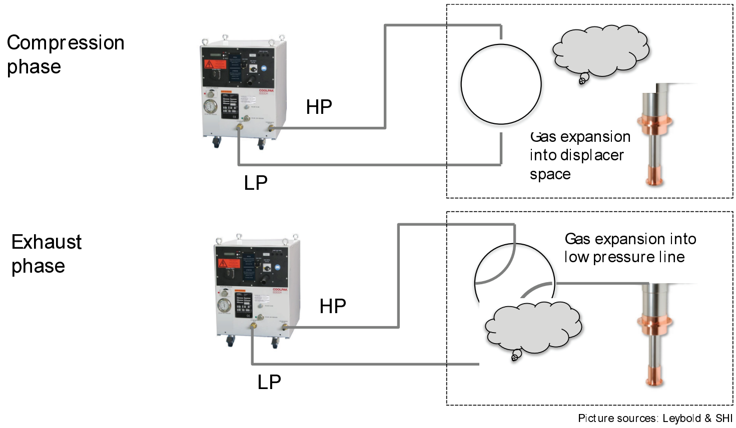

Figure 1. Loss mechanisms due to the use of a rotary valve

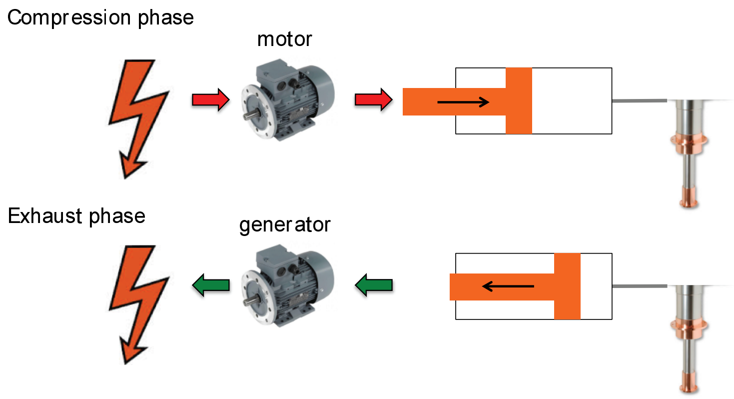

Figure 2: Schematic of a linear compressor driven by an electro-hydrostatic drive and a compression cylinder.

During the compression phase high pressure Helium gas is expanded via the rotary valve into the displacer space. The expansion work of this process is not used and thus lost. The same is true for the exhaust phase. The highly pressured gas is expanded into the low-pressure line. Again the expansion work is not being used.

We propose to use an electro-hydrostatic drive with a compression cylinder to overcome these losses. Figure 2 shows a schematic of the set-up: the motor uses electrical energy to drive some kind of gear or hydraulics. These are then connected to the piston of a compression cylinder. The low frequency pressure wave is directly fed into the cold space of the displacer. In the exhaust phase the pressurized gas drives the piston back and the motor can be used as a generator. In this way the expansion energy of the gas can be recuperated into the power supply. This process also works for systems off-resonance in comparison to e.g. the flexure bearing compressors that rely on running the piston(s) in resonance. In this way one is able to optimize operating frequency and stroke as needed for the cold head with enhanced pV-efficiency.

SYSTEM DESCRIPTION

The initial compressor system and first results have been presented elsewhere[2]. In this paper we report on a modification to the initial system. The Helium compression cylinder with sealed piston was exchanged for an arrangement where the hydraulic piston is directly displacing gas in a cylinder. No seals are used as the clearance between the piston and the cylinder is small, thus resulting in a small dead volume. The new set-up for this second generation is shown in figure 3.

The electro-hydrostatic drive consists of an electrical motor and a gear pump. The gear pump is connected via hydraulic lines to the hydraulic cylinder. The movement of the hydraulic piston is achieved by pumping the oil into one or the other side of the hydraulic cylinder. The speed of the piston is directly proportional to the speed of the electrical motor driving the gear pump, thus allowing for full control over the motion.

A water-cooled aftercooler is used to cool the warm gas from the compression chamber before it goes into the cold head.

The 2-stage 4K GM cryocooler RDK-101 from Sumitomo Cryogenics has been used as a cold head. The rotary valve is bypassed and the internal motor is only used to drive the displacer. The pressure wave was synchronized with the displacer by measuring the displacer position and feeding this back to the motor control via a PID loop. In this way synchronization accuracy of around 1% is achieved. The phase angle between pressure wave and displacer motion can also be varied via software.

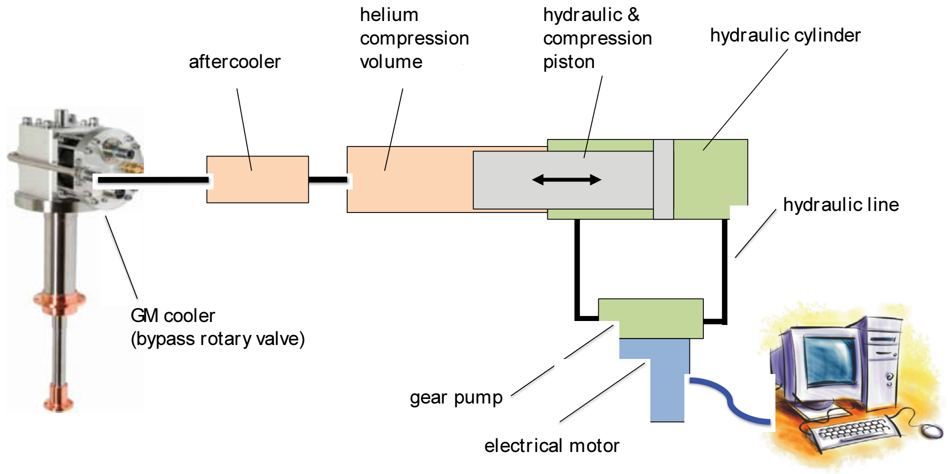

Figure 3: set-up of second generation compressor with cold head

RESULTS AND DISCUSSION

Figure 4 shows the pV-diagram for the RDK-101 cold head as described above operated at a frequency of 1Hz and an input power of 1.4kW. Taking the compression part of the cycle one can calculate the pV-efficiency η_{pV} supplied to the cold head:

$$\eta_{pV} = {}^{P_{pV}}\!/_{P_{\mathrm{el}}}$$

with

$$W_{pV} = -\int_{V_{max}}^{V_{min}} pdV$$

and

$$P_{pV} = W_{pV}\, f$$

where W_{pv} denotes the work per cycle and f the operating frequency of the displacer. An experimental pV-efficiency of near 70% has been measured.

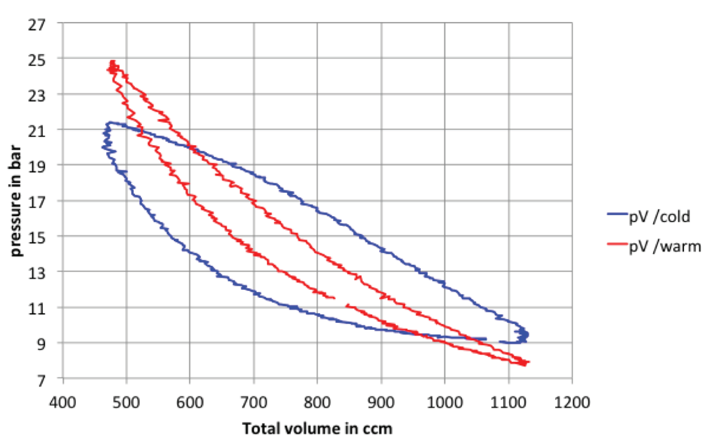

Figure 4: pV-diagram of 2-stage 4K GM driven by the second generation compressor

Although the PV-efficiency of the modified compressor was near 70% compared to 40% for the initial system[2], a lack of expected cooling power in the cold head was observed and is subject to further investigation. Still, this result is very encouraging, as a future compressor product would enable substantial energy savings on the electrical input power as well as for subsequent cooling of the compressor. Future plans also include a third generation that will be completely oil-free.

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1. Y.L. Yu, *Cryogenics* 41 (2001), pp. 513-520.
2. J. Höhne, “High efficiency, low frequency linear compressor proposed for Gifford-McMahon and pulse tube cryocoolers,” *Adv. in Cryogenic Engineering*, Vol. 59, Amer. Institute of Physics, Melville, NY, AIP Conf. Proc. 1573 (2014), pp. 1242-1245.