Low Frequency Stirling Operation of a Two-Stage 4K Cryocooler without Rotary Valve with a Metal Bellows Compressor

J. Höhne

Pressure Wave Systems GmbH
Taufkirchen, Germany

ABSTRACT

The energy efficiency of low frequency GM and GM-type pulse tube cryocoolers is partially limited by the rotary valve[1] to the extent that almost 50% of the input energy is lost. Moreover, there is a desire to build cryocooler systems with less mechanical parts that might fail or need service after a certain time period. Pressure Wave Systems started the development of a metal bellows compressor for low frequency Stirling operation of 4 Kelvin GM and pulse tube cryocoolers without a rotary valve. In this paper we report first results of successfully using a modified version of our commercially available 1 kW PWG500 bellows compressor to directly drive the TransMIT SUSY two-stage 4 Kelvin pulse tube cryocooler in low frequency Stirling mode at around 2 Hz operating frequency. Future work using this technique with 4K GM cryocoolers will be addressed.

INTRODUCTION

Pressure Wave Systems is developing Helium compressors based on electro-hydraulics and metal bellows. One advantage of this technology is, that the helium gas never gets in contact with oil and is always kept clean in the compression process. Oil separators as well as other filter elements are not needed for operation. Moreover, these compressors are orientation independent which makes them very attractive for mobile applications and trouble-free shipping. To optimize energy consumption the electro-hydraulics are inverter driven, which means that the input power can be varied according to the applications. Also, stand-by operation for systems that are not immediately needed but need to be operational within a short period of time can be realized by reducing the power e.g., over night.

A system sketch is shown in Fig. 1. The two cylinders which hold the metal bellows are connected via a hydraulic pump which allows fluid transportation in both directions. Hydraulic oil is used to compress Due to the pressure being in equilibrium on the inside and outside of the bellows, the wall thickness of the bellows can be very thin. Each cylinder has two check valves which are connected to the high-pressure and low-pressure reservoir, respectively. For operation, the oil is flowing from one cylinder to the other via the hydraulic pump. One bellow is being compressed whereas the other one is expanding. Then the direction is reversed, and the other bellow is being compressed/expanded. In this configuration this compressor works like a conventional compressor with supply and return sides. The commercial product has been mainly developed to drive the Sumitomo RDK-101 cold head and has an input power of up to 1.3 kW. Its footprint is 19” 6U compatible.

Cryocoolers 22, edited by R.G. Ross, Jr., J.R. Raab and S.D. Miller

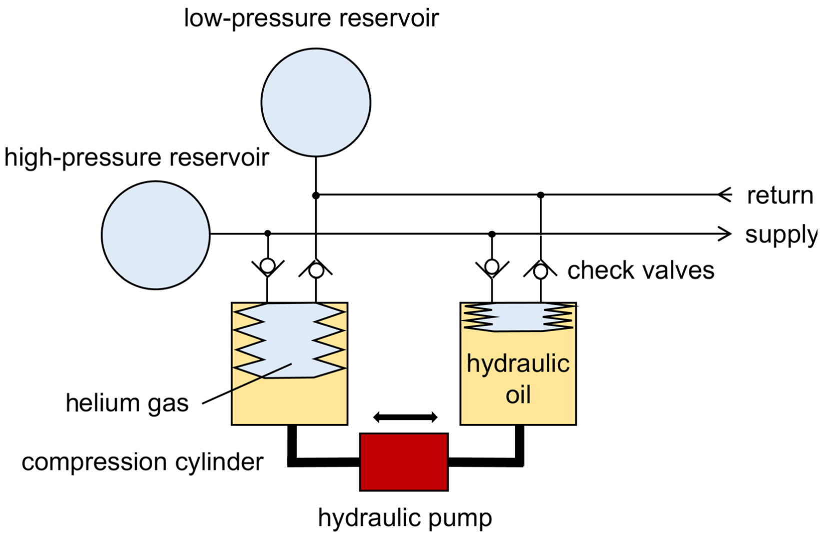

Fig 1. Sketch of bellows compressor

STIRLING OPERATION WITHOUT ROTARY VALVE

To operate the compressor as a pressure wave generator for Stirling operation one only needs one side of the bellows compressor which is the connected to the inlet of the pulse tube system via a heat exchanger. The other side of the bellows compressor is equipped with a reservoir to account for the system pressure (Fig. 2). One of the main differences to rotary valve operation is the pressure wave. As the bellows move forward and backwards the flow is determined directly by this movement. Figure 3 shows the pressure wave during successful operation measured directly at the outlet of the compressor compared to a typical pressure wave generated by a rotary valve.

Figure 4 shows a load map comparison for the TransMIT SUSY 2-stage 4 Kelvin cold head with and without rotary valve. The data for the operation with rotary valve have been taken from the user manual.[2] Electrical input powers were around 1 kW, and operating frequencies were 2.2 Hz for both measurements. Temperatures were measured with a Lakeshore 218 Temperature Controller and individually calibrated Cernox thermometers.

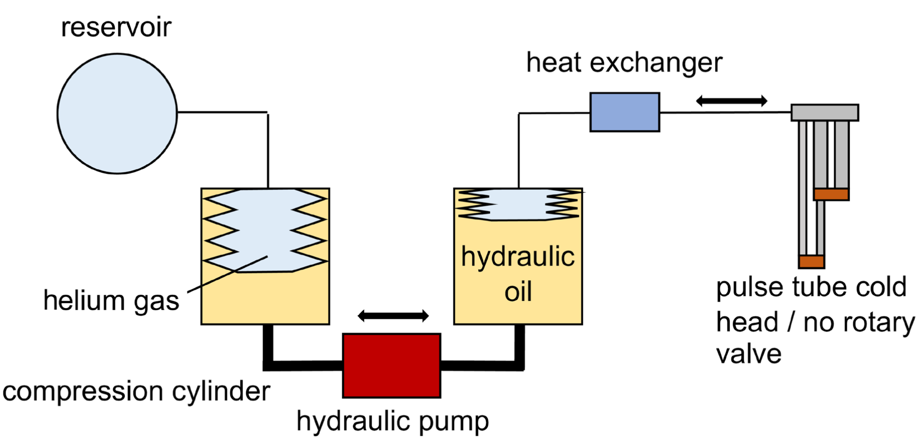

Fig 2. Set-up for Stirling operation of the pulse tube with bellows compressor

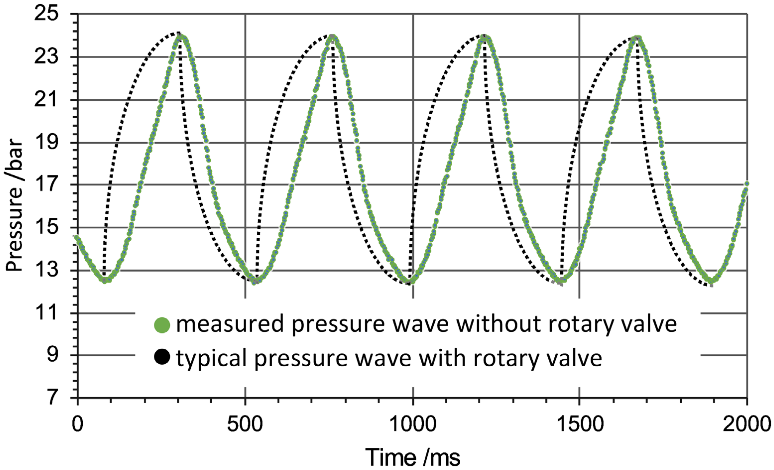

Fig. 3. Qualitative comparison or pressure wave form without rotary valve vs. with rotary valve

DISCUSSION

We have successfully shown that the operation of a low frequency 4 Kelvin pulse tube cold head is possible without the rotary valve using a metal bellows compressor. Moreover, the bellows compressor technology has matured to a level where long term uninterrupted and maintenance-free operation of these systems are within reach. We were not able to show higher energy efficiency in our first experiments and have identified the following routes for improvement: the reservoir is also pressurized during the operation which leads to extra energy consumption. It was seen that changing the size of the reservoir also changed the energy consumption. Ambient operation conditions with lab temperatures of > 30° C and helium inlet temperatures of > 45° C led to high heat load on the first stage of the regenerator and the pulse tube heat exchangers. A heat exchanger with higher efficiency might be necessary. The pressure wave characteristics are different from operation with a rotary valve. Further discussions and measurements are needed to match the pulse tube cold head and the pressure wave characteristics.

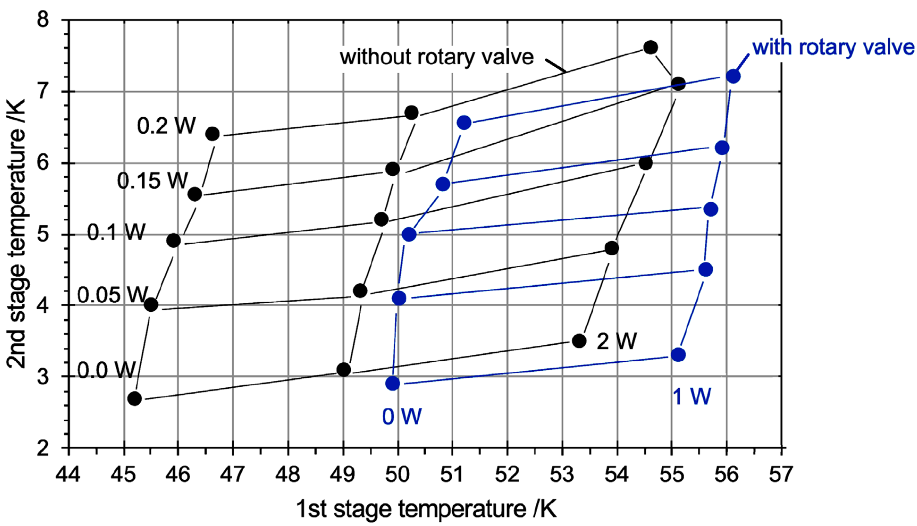

Fig. 4. Load map comparison for operation with and without rotary valve

OUTLOOK

Stirling operation of low frequency 2-stage 4 Kelvin cryocoolers opens up new opportunities for compact and energy efficient cooling systems. Especially when aiming for higher efficiency, using a GM cryocooler without a rotary valve should even be more promising, as the GM cold head has less cold volume and needs less gas flow. On the other hand, the synchronization of the compressor stroke with the displacer movement is needed.

ACKNOWLEDGMENT

The author would like to thank M. Bühler from Low Temperature Solutions UG, Ismaning, for many extensive discussions and practical help. The speed and accuracy in making mechanical parts by G. Töpelt is greatly appreciated. This work was happily supported by WMH, FH and JH.

REFERENCES

1. Y.L. Yu, "Thermodynamic analysis of GM-type pulse tube coolers," *Cryogenics,* 41 (2001) pp. 513-520.
2. *PTD SUSY (SN78) manual*, TransMIT – Center for Adaptive Cryotechnology and Sensors, (2018).