

Development of Single Piston Moving Magnet Cryocooler SX020

M. Mai, C. Rosenhagen, I. Ruehlich

AIM INFRAROT-MODULE GmbH,
Theresienstr. 2, 74072 Heilbronn, Germany

ABSTRACT

State of the art Mid Wave IR-technology has raised typical FPA temperature from 77K to 130-150K (high operation temperature - HOT). This trend will continue by current developments until FPA temperature will be in the range of 150-200K for future Mid Wave detectors.

AIM has developed a compact SX030 cooler, optimized for FPA temperatures of about 140K (shown at SPIE conference in 2012). The SX030 cooler incorporates a high efficient single piston driving mechanism with a passive balancer for the lowest exported vibration levels. For future HOT application even this cooler will be oversized. Thus AIM has developed the next member of the SX cooler family, the SX020.

With an outer diameter of less than 27mm and a length of less than 60mm SX020 is the smallest compressor AIM has ever developed.

It is a single piston Moving Magnet driving mechanism and an internal passive balancer. AIM has developed a novel passive balancer concept, which is implemented into SX020 housing. Following the modular design principle of SX cooler family the SX020 supports the AIM ¼" displacer but also an upcoming ultra-short 5mm displacer. The cooler is driven by a compact and highly efficient digital cooler electronics, DCE025.

This paper gives an overview on the development of this very new compact single piston cryocooler. Technical details and performance data will be shown.

INTRODUCTION

Some years ago the cryocooler was the determine component of an infrared system. The weight of the system was mainly driven by the weight of the cooler. The lifetime of the system was limited by the lifetime of the cooler and the power consumption was mainly driven by the efficiency of the cooling system. Linear cryocoolers with a maximum input power of 60W have been common. At this time AIM started to develop long life cryocoolers. The SF100 uses moving magnets for the first time instead of moving coils and flexure bearings [1]. This cooler was designed to meet the One Watt Linear (OWL) specification with an increased lifetime of about 20,000h. Then, the HOT-Technology radically changed the market for tactical cryocoolers. An increased in operating temperature of the detectors led to smaller and smaller coolers.

AIM answered to the new demands with the SF070 in 2009 [2] and the SX040 in 2011 [3]. Two years ago AIM presented the first single piston compressor with a passive balancer, the SX030 [4]. The design goal was to produce a compact cryocooler for a typical detector

temperature of 140K with a mass of just one fifth of the SF100. Further developments at the displacer lead to a cryocooler that can also be used for under 100K for most applications.

Recent developments in HOT-Technology and shorter wave length led to even higher detector temperatures. In addition, the trend to a smaller detector pitch decreases the thermal load of the dewar. Thus even the SX030 will only operate in a part-load range, a range with decreased efficiency because of the decreased piston stroke.

In 2013 AIM started the development of a next smaller cooler, SX020. This cooler will fit to future demands for a tactical micro IDCA's with lowest size, weight and power (SWaP).

COMPRESSOR DESIGN

There are tactical cryocooler with several different design principles available on the market. Moving coil or moving magnet, Flexure Bearing supporting pistons or a spiral spring, dual piston or single piston design are some examples. AIM performed a study of the design principle at the beginning of the project. The intention was to find the optimal solution for this micro cooler. Many design concepts were developed and compared with respect to performance, size, weight, cost and manufacturing issues. A single piston moving magnet compressor with an internal passive balancer was found to be the optimal design for the new micro cooler.

The main advantage of the single piston design is a significant benefit in production cost as the linear motor including coil, magnet and soft iron as well as piston and sleeve are needed only once. In addition there is only the friction of one piston, which becomes more important when the cooler is miniaturized.

The principle design of the SX020 is comparable to the design of the SX030. The compressor is basing on a moving magnet driving mechanism with coils outside the helium vessel. The same driving mechanism is also used in other AIM cryocoolers from the SF- and SX-family. High performance magnets are fully encapsulated to avoid damage and the outgassing of organic materials, one of the basic assumptions for a long life cooler. Another one is the high performance piston coating which allows a lifetime in excess of 30,000h.

Compared to the SX030 thee detail solution had to be changed due to the lower outline dimension of the new compressor. The relative orientation of transfer line and fill port can be changed to meet the customer's requirements.

Figure 1 shows the SX020 with ¼" coldfinger, and Figure 2 shows the outline dimensions of the compressor. Table 1 shows the design features of the new SX020 compressor.

PASSIVE BALANCER DESIGN

Because of the absence of an opposed piston a single piston compressor needs a passive balancer to reach low vibration output forces. For the SX030 AIM has developed a new balancer principle. The design of this balancer also allows the integration into the compressor housing, what was done for the SX020.



Figure 1: SX020 with ¼" coldfinger

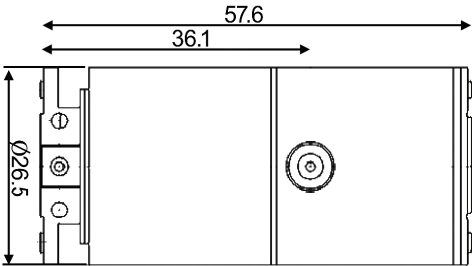
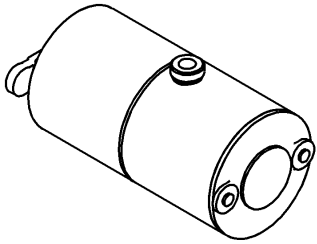


Figure 2: Outline dimension of SX020 [mm]

Table 1: Design feature of the SX020 compressors

| Technical data | Value |  |
|---|----------------------|--|
| Length of compressor including passive balancer | 57.6mm (2.27 inches) | |
| Diameter of compressor | 26.5mm (1.05 inches) | |
| Weight of compressor including balancer | 158g (0.35lbs) | |
| Total weight of cooler including compressor, passive balancer, fixture, transferline and ¼” displacer | 240g (0.53lbs) | |

The passive balancer is a mass spring system which is adjusted to eliminate the vibrations of the compressor. The springs of the damping system are flexure bearings. The design is similar to AIMs Flexure Bearing compressor springs [1], [2].

The relatively small outer diameter of the system the compressor (<28mm) leads to a small possible stroke for the flexures. For an ideal balanced system the product of stroke and mass will be the same for the compressor piston and the passive balancer. Just increasing the mass of the balancer is not a solution. To keep the damper in resonance the spring rate also needs to be increased, and it does not leads to a reduction in the stress on the flexures. Thus the demanding part of SX020 compressor development was to get a flexure spring design with the correct axial and a high radial spring rate within the endurance range of the spring material.

For an optimal design the thermodynamic part and the passive damper need to be regarded in combination. Both needs to reach their maximum stroke at the same input power. Because of resonance condition of both parts the optimal solution also depends on operating frequency.

There is a need for a flexible mounting of the compressor allowing a small movement to get the balancer excited because of the working principle of the passive damper. Thus a clamping of the compressor is not possible. The compressor itself needs some freedom of movement. This movement will drive the balancer. Thus it is necessary to fix the compressor by a flexible element. This element needs to be flexible along the compressor axis to allow the necessary movement of the compressor. It also has to be stiff in the compressor’s lateral axis to withstand mechanical shocks/vibration etc. The SX020 can be mounted via leaf springs to a compressor mounting plate. The compressor plate (Figure 3) allows an easy system integration of the compressor with a four thread interface.

Due to this mounting principle, the conductive heat removal from the compressor is not feasible. A convective heat removal is sufficient because of the very small input power of the cooler. A nominal input power of less than 2W into the compressor leads to a heat dissipation at the compressor housing of less than 1W.



Figure 3: Compressor mounting plate

COLDFINGER DESIGN

In an integrated detector cooler assembly the coldfinger is also the inner dewar. Therefore the mechanical fixation of the detector is an important assignment of the coldfinger. Due to the small pixel pitches, even movements of a few microns lead to blurred images. The coldfinger needs to avoid such movements even when in the presence of high mechanical vibrations. Beyond that the coldfinger top needs to provide a sufficient area to mount the detector. Thus the coldfinger diameter cannot be designed to reach the highest efficiency.

AIM is using a modular approach, allowing the use of a 1/4" Stirling expander with 5 different compressor types. The main advantage for the customer is to use the same dewar for different applications. When using a LWIR detector the dewar and matching Stirling expander can be used with powerful compressors like SF070 or the SX095. This provides the shortest cool down times and highest MTTF despite low detector temperatures. A MWIR detector can be used with the same type of dewar and identical expander in conjunction with compressors SX040 or the SX030 [4]. For HOT MWIR or SWIR applications both SX030 and the SX020 can be used.

With the SX020 compressor AIM has a compact compressor available. To build up a very small IDCA, an expander with a reduced overall length is necessary. Therefore AIM is developing a short version of its 1/4" coldfinger.

In the expander AIM is using a single piece shell of a high performance plastics material. Thus reducing the length to meet a specific dewar length can be done quite simply by adjusting the length of one part only. Figure 4 shows a comparison of the outline dimension of both versions. A picture of the SX020 cryocooler with a short 1/4" coldfinger is shown in Figure 5.

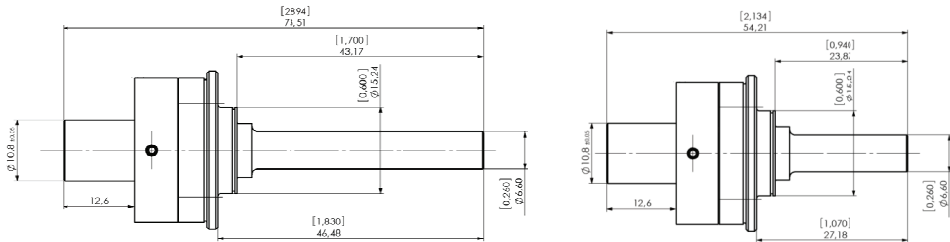


Figure 4: Outline dimension of AIM 1/4"coldfingers (standard left, short right)



Figure 5: SX020 with short 1/4" coldfinger

The AIM ¼” coldfinger initially was designed for cold tip temperatures of about 80K. The length of the regenerator is quite long to reduce the heat conduction losses. For applications operating at 140K or above the heat conduction losses become less significant. Obviously the losses will increase when the coldfinger length is shortened, but pressure drop losses will be decreased. Thus, the impact of the cold finger length to the cooler performance will decrease for higher cold tip temperatures.

To achieve even more compact IDCA’s AIM is developing an ultra short coldfinger with a total length of about 35mm. For this coldfinger a new design was necessary to reduce the size without increasing conduction losses significantly. With this design it is possible to use almost the full coldfinger length for the regenerator matrix.

PERFORMANCE DATA

The first prototypes of the SX020 are build and performance tested. The performance data of the cooler with the AIM ¼” standard Stirling expander at an ambient temperature of 23°C are shown in Figure 6. With a standard size detector operating at 160K the power consumption of the cooler should be less than 2W without and 2.5W including a cooler electronics. The data for high ambient temperature (71°C) are shown in Figure 7.

The compressor was designed to cooling an infrared detector operating at 160K. Depending on detector size, thermal load of the dewar and ambient temperature range it is possible to use the cooler down to 140K. For operation at room temperature even 120K should be possible, if the application has no demand for a fast cooldown time.

As described before AIM is developing a short version of its ¼” Stirling expander. The design phase is finished, the mechanical parts are ordered. Based on the AIM simulation model the predicted performance of the SX020 with AIM ¼” short coldfinger is shown in Figure 8. Measured performance values will be available soon.

SUMMARY

A new ultra-compact single piston linear cooler for HOT IDCA’s has been developed. This cooler is designed for cooling infrared detectors at 160K. The compact size as well as the efficiency of the cooler meet the SWaP requirements for state-of-the art cooled IR technology.

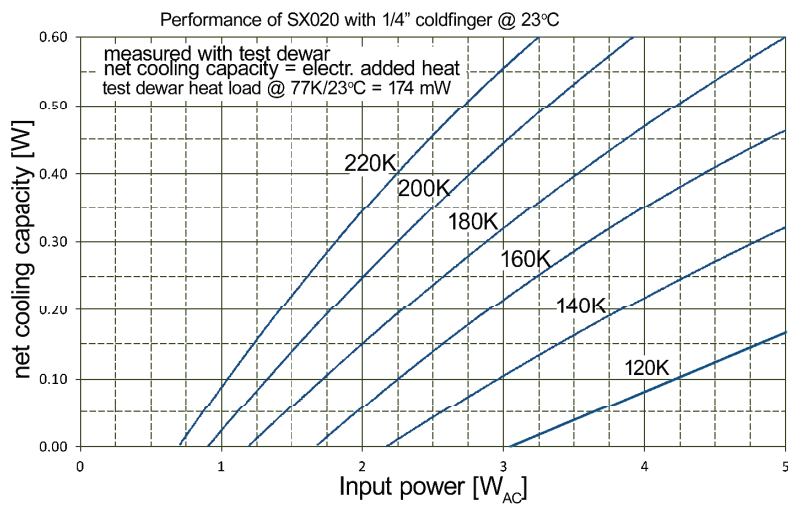


Figure 6: Performance of SX020 with ¼” coldfinger @ 23°C

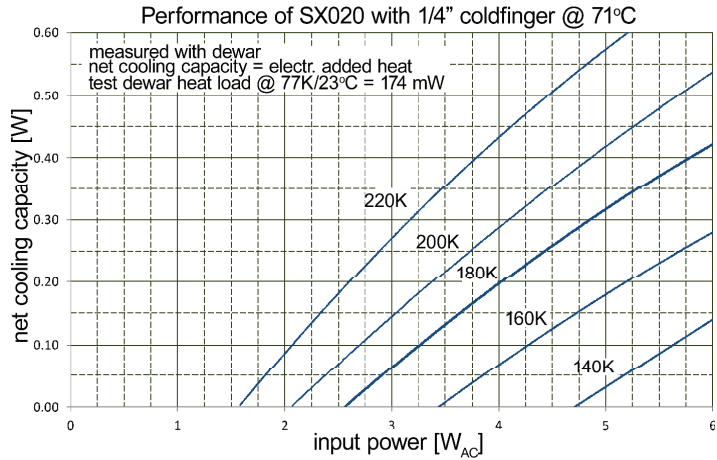


Figure 7: Performance of SX020 with 1/4" coldfinger @ 71°C

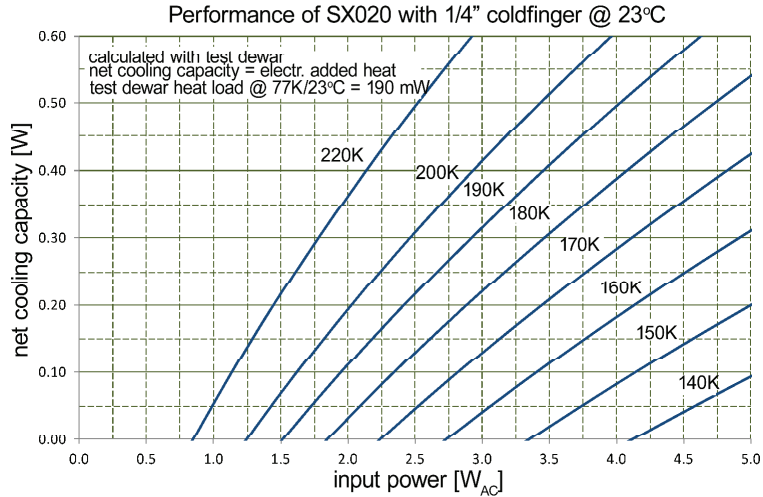


Figure 8: Predicted performance of the AIM 1/4" short coldfinger

With a moving magnet linear drive mechanism and high performance piston coating the cooler reaches MTTF lifetimes in excess of 30,000h. Thereby the cooler is with a weight of 160g, a length of 60mm and a diameter of 28mm more compact than most dewar assemblies.

A short version of AIMs standard 1/4" coldfinger will decrease the size and weight of the dewar assembly and will enable a build-up of the smallest IDCA solutions.

With an AC power consumption for a typical 640x512 IDCA of < 1.2W at 180K the cooler is also an ideal solution for handheld application. For these applications, the lowest exported vibration are required. Thus a passive balancer is integrated into the compressor. This technology is also most competitive to reduce production cost.

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