**Scroll Compressor for Mars Atmospheric Acquisition.** John Wilson[1] and Bryce Shaffer[2], [1]Air Squared, Inc. 510 Burbank St., Broomfield, CO 80020 j.wilson@airsquared.com, [2]Air Squared, Inc. 510 Burbank St., Broomfield, CO 80020, bryce@airsquared.com

**Introduction:** In Situ Resource Utilization (ISRU) technologies are critical to the advancement of human missions to extraterrestrial bodies. For example, in a Design Reference Architecture mission study from 2009, it is estimated that ISRU technology for generating Oxygen will reduce the Landed Dry Mass requirement from 100 to 70 metric tons. ISRU processes are achieved by collecting, separating, pressurizing or processing materials found in the environment of extraterrestrial bodies.

In the MOXIE experiment aboard the M2020 mission to Mars, gasses from the Mars atmosphere are collected and compressed for reaction in a Solid Oxide Electrolysis (SOXIE) stack. The goal of this project is to develop and demonstrate flight hardware which can ingest Martian atmosphere and convert it to $O_2$ and CO through solid oxide electrolysis. The Oxygen can be used to for breathable air for astronauts, and potentially to generate fuel for any return mission. There are several ways to capture and pressurize carbon dioxide, including freezing at cryogenic temperatures, mechanical compression, and absorption. Completed studies on each approach have generally favored cryogenic temperature and mechanical compression solutions. A key advantage of mechanical compression is reduced complexity.

Air Squared has been working with JPL and NASA on developing flight-ready hardware for MOXIE. Air Squared's contribution to this system is a compressor which compresses $CO_2$ from as low as 5 Torr up to 760 Torr. This approach can best be summarized as a mechanical compression approach where just collection is required from the compressor. Because solid oxide electrolysis can be accomplished after the compressor with trace amounts of $N_2$ and Ar present, separation of these gasses is not necessary

**MOXIE Requirements:** On the M2020 science rover, resources such as mass and power are constrained when compared to what would be required for oxygen production on a human-scale mission. The volume available to the compressor was severely limited in 2 dimensions. Restrictions on all these resources drove design choices and compromises in compressor size, operating speed, and performance.

*Table 1: Compressor Requirements:*

| **Compressor Mechanical Requirements** | |
|---|---|
| Dimensions [mm] | 150 x 96 x 175 |
| Mass [kg] | 1.8 |
| **Compressor Performance Requirements** | |
| Gas Inlet Pressure [Torr] | 7 |
| Gas Inlet Temperature [C] | -45 to +55 |
| Gas Outlet Pressure [Torr] | 760 |
| Mass Flow Rate [g/hr] | 60 |
| Life [hrs] | 246 |

**Scroll Compressor Technology:** The mechanism that feeds the MOXIE experiment with Martian atmosphere comprises an electronically commutated (EC) direct current motor coupled to a "scroll pack" gas compressor. There is one compressor assembly (motor plus scroll pack) in the MOXIE experiment. The compressor is of the scroll type, with a moving (orbiting) scroll orbiting a stationary (fixed) scroll. The motion of the orbiting scroll is controlled by ball-bearing mounted idler shafts. A brushless DC motor provides the rotational power. Figure 1 shows an overview of the scroll compressor assembly.

*Figure 1: P09H026A-A01 Scroll Compressor*

The orbiting scroll operating principle can be seen below in Figure 2. The fixed scroll is represented by the white involute, which is stationary during operation. The orbiting scroll, shown in blue, orbits in a circular motion about the fixed scroll involute. The scrolls capture pockets of gas (Orbiting-1) in the two outside chambers and compress that gas radially inward until the pocket discharges out the center of the scrolls (Orbiting -3). The process continues to expel gas at the center, while a new cycle of compression begins with fresh pockets of gas at the outer diameter (Orbiting-4).

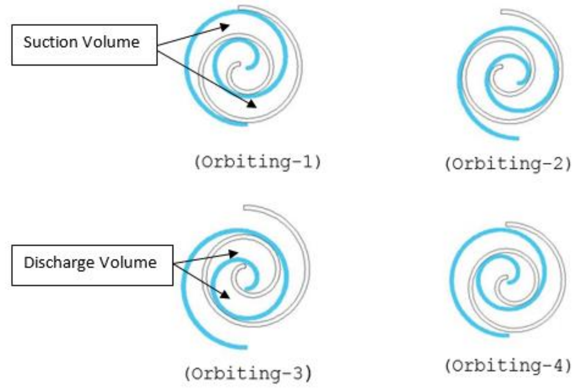


*Figure 2: Orbiting Scroll Operating Cycle*

The scrolls are phased with one another using three idler shafts show in Figure 3, which have an offset shaft on a precisely toleranced "eccentric". The idler shafts not only control the phasing of one scroll relative to the other, they also control the gap between the two scrolls. It is critical that the idler shaft prevent the scrolls from touching for this compressor design.

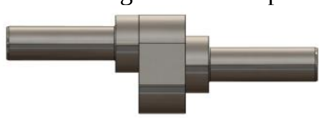

*Figure 3: Scroll Compressor Idler Shaft*

**Prototype Development Plan:** Air Squared first provided a prototype compressor to JPL to permit demonstration of proof of concept. This prototype design was based on previous Air Squared vacuum pumps, which also require a high built-in volume ratio. The volume ratio for a scroll compressor is the ratio of the suction volume (displacement) to the discharge volume. The prototype was inserted into the MOXIE testbed at JPL, where its performance met all functional requirements.

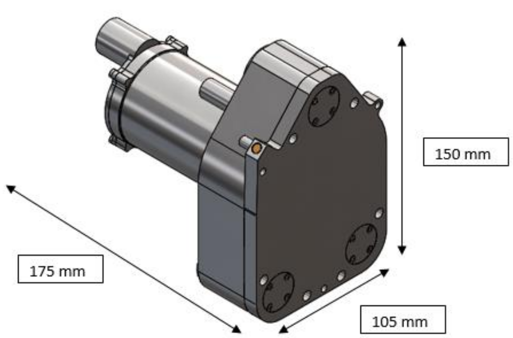


*Figure 4: Prototype Scroll Compressor*

One major discovery found during testing of the prototype at JPL was the pressure oscillations that naturally occur in a scroll compressor. It was feared that these may be detrimental to the SOXE, as it had never been tested with a pulsating input flow. To reduce these pressure oscillations, a check valve and viscous flow control device (VFCD) were inserted downstream of the compressor. These additional components not only prevented the pressure pulsations, but they also help prevent backflow through the compressor.

**Flight design and development:** With the validity of the MOXIE architecture firmly established, flight design proceeded with tighter restriction on the compressor's footprint, mass, and power. With 10 millimeters less to work with on the width of the compressor (95 mm), the involute needed to be resized from the prototype (105 mm width).

The major consequence to the performance was a lower overall mass flow rate, which was reduced from 100 g/hr in the prototype to 84 g/hr for the flight unit for the 7 Torr, 20 C inlet condition.

Another major change between the prototype compressor and flight compressor is the motor. The compressor still uses a BLDC motor, but it is a housed motor design instead of a frameless motor which was used in the prototype. The major concerns with the new motor design are heat transfer from the motor, increased motor mass and additional tolerance stack-up with the motor shaft.

With the de-rated maximum case temperature of the hall sensors set to 105 C, getting the heat out of the motor through the housing and fixed scroll into the heat sink became a challenge. The heat transfer concern is being mitigated with the use of an aluminum thermal sleeve, which is bonded to both the motor housing and the compressor housing. This sleeve removes heat from the hottest part of the system, the stator, and better conducts it down through the housing to the fixed scroll.

**Conclusion:** The major challenges that arose during the design and testing process was the heat removal and grease retention. The heat removal from the motor was improved by adding an extension to the aluminum compressor housing to increase the conductance from the motor housing to the MOXIE baseplate, or heat sink. The grease loss concern was mitigated by providing vent holes for all trapped air pockets between bearings. Analytical prediction of bearing life suggested that the motor bearings, with their larger diameter and higher ball count, could encounter lubricant degradation in life testing.

A lesson learned from this development is that early brassboard or prototype testing is valuable. Integrating a custom motor design to a scroll compressor, modified with many customer-directed features, is not a predictable, linear process. An early evaluation model of the flight design is always desirable!