Zero Boil Off Compressor Based on MICA Actuators

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Abstract

A reed valve compressor technology for future science spacecraft application, is being developed by CEDRAT TECHNOLOGIES (CTEC), based on the very compact and high-power MICA300CM actuator (**M**oving **I**ron **C**ontrollable **A**ctuator). The present publication details the compressor breadboard design and test results, manufactured in the frame of an ESA Technological Research Program (TRP), for the testing of a Zero Boil Off Hydrogen storage demonstrator. The test results presented have been realized at compressor level with Helium gas at CTEC facilities, and the full 20K Hydrogen storage demonstrator is soon to be tested.

1 Demonstrator scale rationale

The objective of this TRP project is to demonstrate by test, at reduced scale, the zero boil off principle of a 20K Hydrogen storage, on board a science spacecraft, equipped with a Joules Thomson Compressor. The demonstrator aims at driving the compressor to maintain constant the pressure inside the 20K storage, by liquefying continuously the hydrogen vapor boiled off by the spacecraft heat losses.

The demonstrator scale chosen is at 1/3 of a flight scale requirement, which considers realistic a 20W boil off heat load onto a 20K liquid hydrogen flight storage. Such an hypothesis on a long duration flight of a spacecraft allows considering both options of a zero boil approach or a reduced boil off one assuming little wasting of Hydrogen. Therefore, in order to demonstrate both principles the demonstrator scale has been set test a 5W zero boil off approach and reduced boil off beyond.

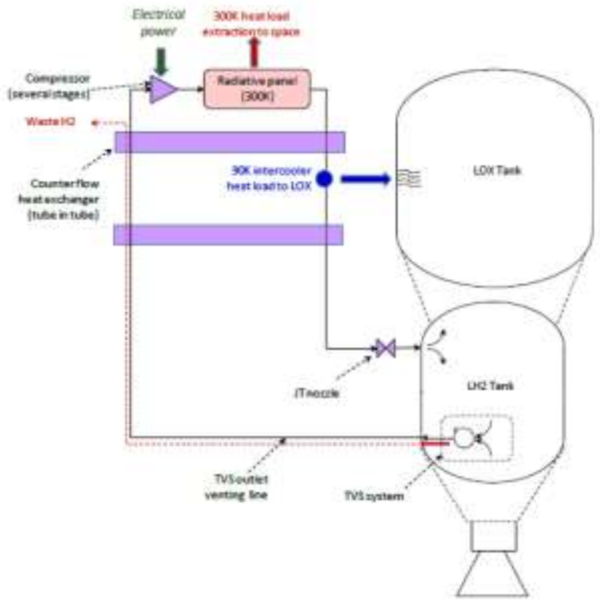

Figure 1 Zero & reduced boil off test principle

2 Breadboard compressor design

The compressor required for this demonstration has been designed to provide a 0,08g/s hydrogen flow rate at 50bars, obtained with two compression stages, each of compression ratio of 3, and for a total electrical power installed of 400W. Internal fluid loops have been implemented to reject the compression heat power, and to obtained an outlet gas temperature about 30°C.

Figure 2 Compressor breadboard with two stages

2.1 MICA300CM Flexure bearing actuator

The compressor has been designed with two custom MICA300CM actuators (**M**oving **I**ron **C**ontrollable **A**ctuator), one for each stage, achieving 80% of efficiency including both Joules and Iron losses. Such a high performance is achieved thanks to the very high force to compactity ratio, achieved by such actuators, and by an optimised design of the magnetic material to reduce eddy current losses.

Figure 3 Custom MICA300CM actuator

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The actuators have been designed and built to be insensitive to Hydrogen embrittlement, and to be compatible with ATEX design constrains within hydrogen test zones. The materials have been carefully selected to be compatible with hydrogen, and the coil, as well as all electrical part have been located outside the pressure vessel with potting, and metallic housing, to remove any oxygen from air, in case of hydrogen leak on the test zone.

Figure 4 MICA300CM with coil outside pressure vessel

The actuators are based on infinite life, and frictionless flexure bearings inherited from CTEC space technology. The ongoing fatigue tests on the stand alone version of the MICA300CM flexure bearings are now achieving 3 years of nonstop operation at 30Hz full stroke of +/-6mm i.e. more than 3.10^9 fatigue cycles achieved.

Figure 5 Flexure bearings fatigue test running since 2017

2.2 Reed valves and gas bearings

The compressor design has been based on advanced flapper reed valves developed by CTEC, and piston gas bearing, which allows achieving a long operational life duration without maintenance of several years, and without lubrication.

The flapper reed valve is a key component of a compressor, which prevent from gas back flow, and ensure the pressure ratio build up, at a high frequency of 50Hz. Together with the flexure bearings, the reed valves have been designed for infinite fatigue lifetime.

Figure 6 Flapper reed valves

Each compressor stage is based on a double effect configuration, i.e. two pistons driven by each MICA300CM actuator. In order to achieve high compression ratio with a piston, a tight tightness between piston and cylinder is required, with piston rigs which may wear over time, and may reduce the efficiency of the compressor. In order to avoid reduce drastically reduce this wearing, CTEC has developed a gas bearing technology which acts as a lifting force between the pistons and the cylinders, and reduce the piston wearing over time, and eventually suppress it (to be demonstrated on further development phases not foreseen in this project). The gas bearing principle is based on micro-injectors, machined onto the pistons, that allow re-injecting a calibrated flow, at sonic thrust velocity condition, from the compressor stage outlet pressure. The MICA300CM actuators have been sized to provide the addition compression and flow power, required for the gas bearings.

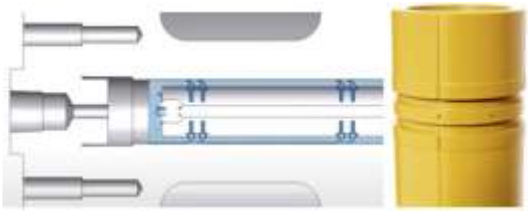

Figure 7 Gaz bearing injectors machined onto the pistons

More details on this compressor technology can be seen on the following Youtube video, as well as on the stand alone MICA300CM actuator.

https://www.youtube.com/watch?v=sX_T_6zUdQ4
https://www.youtube.com/watch?v=zTbBZd4UENs

2.3 Power and pressure flow sizing

The compressor power was sized based on the analysis of the test bench demonstrator Joules Thomson liquefier, with a pre-cooling intercooler at 80K. The following table shows the compressor power requirements, as well as pressure flow requirements as function of the expected boil off rate of the test demonstrator. The compressor was sized for nominal power of 400W and extended power of 500W.

Heat Loss (w)	Comp. Power (W)	Comp. Flow (g/s)	Pressure (Barsa)
5	380	0.080	50
10	388	0.082	49
20	402	0.087	47
30	412	0.091	45
50	429	0.097	43

Figure 8 Compressor pressure flow sizing

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3 Test results

3.1 MICA300CM actuator test results

Prior to integration into the compressor the MICA300CM actuators performances have been tested. The following figure show the force measurement as function of the position. The compressor for requirement is of 300N, whereas the test results shows that more than a twice of this force can be provided by the actuator.

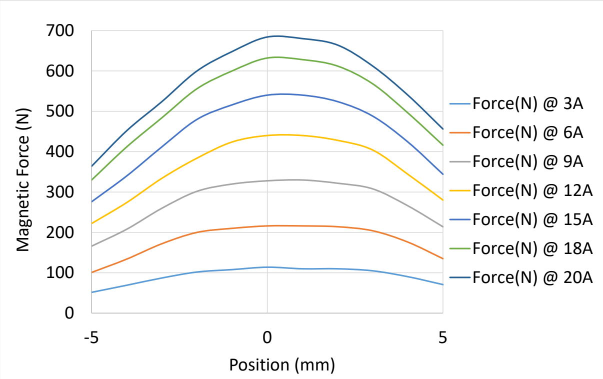

Figure 9 MICA300CM actuator force measurement

In addition to the force test measurement, the efficiency of the MICA300CM actuator was not tested in this project but was tested on another CNES R&T project for a space cryogenic cooler application of smaller power. The efficiency achieved by the MICA300CM in this other custom configuration was 80%.

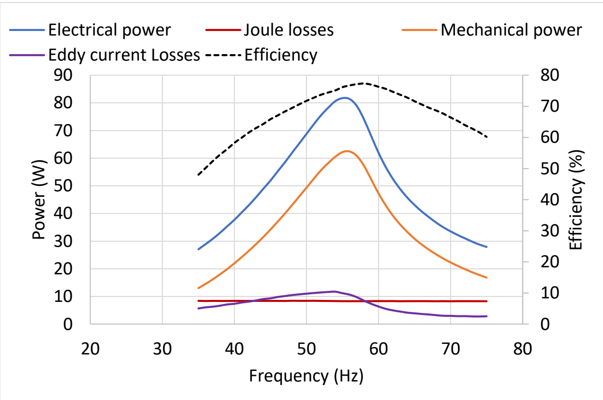

Figure 10 MICA300CM efficiency measurement

The following table summarizes the difference between the stand-alone version of the MICA300CM and the Hydrogen compressor version. The mass of the compressor version is higher due to the 100% built-in stainless-steel housing for hydrogen embrittlement phenomena constraints, and due to the 100bars pressure sizing leading to high thicknesses.

	MICA300CM	MICA Compressor H_2	Unit	Comment
Diameter	100	150 (1)	mm	[1] Compressor Interface included
Height	120	175 (1)	mm	
Total mass	2.62	19.6 (1)	Kg	
Mobile mass	0.58	2.1 (1)	Kg	
Resistance	0.3	0.399	Ohm	
Inductance	12	15.7	mH	
Nominal constant	33	36.1	N/A	
Nominal force	300 (2)	361	N	[2] @9A; 333N @10A
Peak Constant	30	33.6	N/A	
Peak force	540 (3)	672(3)	N	[3] @ twice nominal current

Figure 11 MICA300CM efficiency measurement

3.2 Compressor pressure flow tests

The compressor was tested at CTEC facilities with helium gas prior to sending to Hydrogen test zone. Both stages have been tested individually at nominal pressures. The results here under shows at 5 A input current a compression ratio of 3 on the low-pressure stage, and 2.8 on the high-pressure stage.

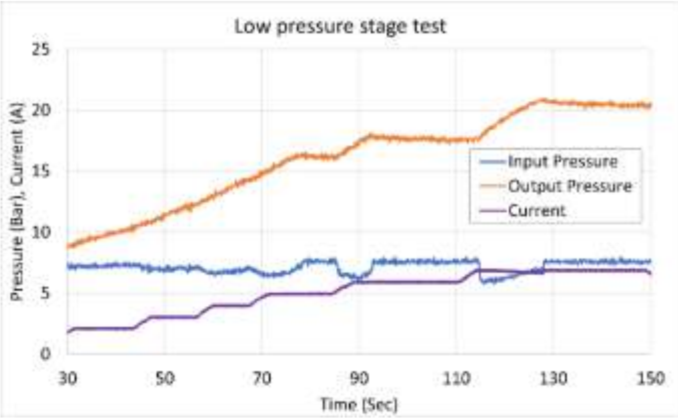

Figure 12 Low pressure stage pressure ratio test

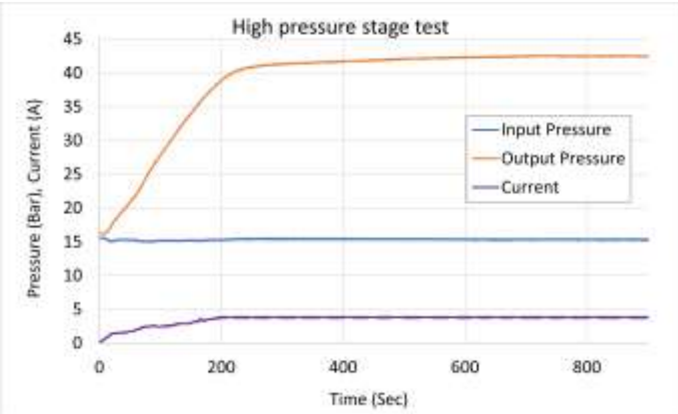

Figure 13 High pressure stage pressure ratio test

Prior to delivery to hydrogen test zone the two stages have been tested in coupled condition with the drive electronics and acquisition system. The drive electronics used are the CSA96 from CTEC design for the MICA300CM. The following test results performed at 20bars output pressure have allowed to demonstrate the stability of pressures and temperatures over time prior to tests in Hydrogen test zone.

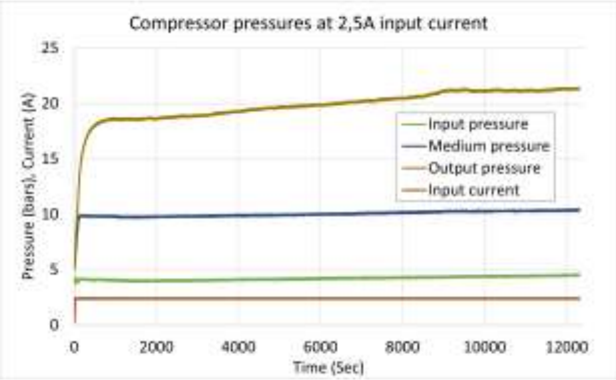

Figure 14 Pressure stability over time

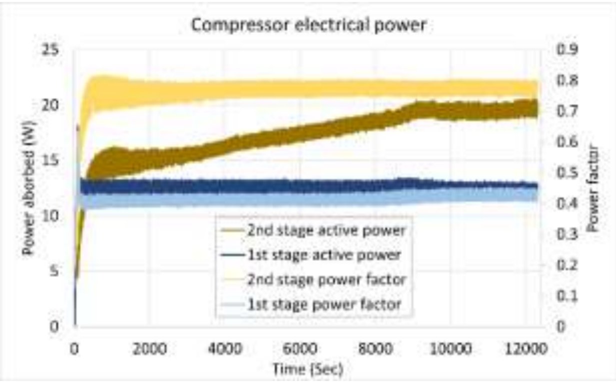

Figure 15 Electrical active power measurement

The temperature stability over time is a key test results due to the high electrical power absorbed, converted into compression heat, and actuators' joules heating. The results have shown that the temperature where stable, allowing a nonstop operation over very long duration without heating issues.

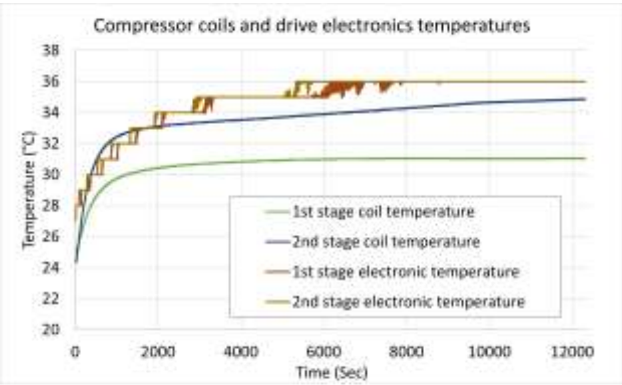

Figure 16 Temperature stability over time

The compressor system was therefore successfully tested in Helium at CTEC and is soon to be tested connected to the Hydrogen zero boil off demonstrator in Hydrogen test zone.

4 Literature

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