

APU stack test standards

D1.3



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Abbreviations

Abbreviation	Long Version
APU	Auxiliary power unit
g	9.81 m ² /s

1 Purpose

The purpose of this deliverable is to define criteria and tests in order to ensure the compliance of a stack with the DESTA APU. Stack manufacturers can use the criteria defined in this document to verify that their stack is suitable for the application within the DESTA APU.

2 System compatibility

2.1 Stack performance

2.1.1 Testing conditions

The stack shall be tested according to the load profile shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** The gas supply shall comply with the values marked in Table 1. Heating and cooling of the stack shall be achieved via the cathode air

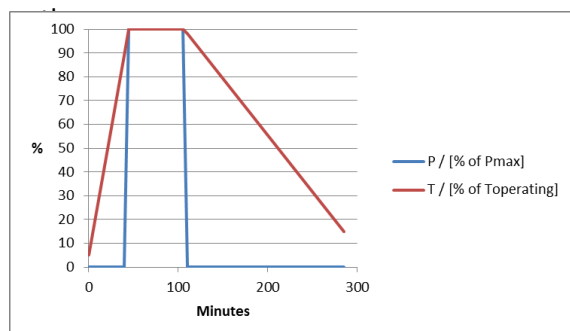


Figure 1: Test profile for the stack performance.

Media supply					
Anode			Cathode		
Max. gas inlet temperature	750	°C	Max. gas inlet temperature	700	°C
Gas inlet pressure	0.11	Bar(g)	Gas inlet pressure	0.14	Bar(g)
Flow rate	137.8	NI/min	Flow rate	775.4	NI/min
CO	13.7	mol%	Air	100	mol%
CO ₂	9.8	mol%			
H ₂ O	11.3	mol%			
H ₂	15.4	mol%			
N ₂	49.8	mol%			

Table 1: Media supply for the performance

2.1.2 Acceptance criteria

Stack heat up time to operating temperature	< 45	min
Anode outlet temp range	650-850	°C
Cathode outlet temp range	780-850	°C
Stack gross power	≥ 3675	W
Current density at 0.75 V/cell	≥ 0.3	A/cm ²
Max. fuel utilisation	85	%
Max. air utilisation	11	%

2.2 Packaging and power density

2.2.1 Testing conditions

The stack shall comply with the following criteria for packaging and power density. Per definition the adapter plate is situated at the bottom of the stack (width and length), however the stack shall be mountable in any direction. The power densities are to be calculated at the maximum load point according to 2.1.1.

2.2.2 Acceptance criteria

Dimensions (width x length x height)	250 x 250 x 300	mm
Weight	≤ 15	kg
Volumetric power density	≥ 250	W/l
Gravimetric power density	≥ 250	W/kg

2.3 Stack pressure drop & gas tightness

2.3.1 Testing conditions

The anode and cathode shall be fed a gas equalling the amounts provided in Table 1 and the leak rate from the anode to the cathode, and cathode to anode, shall be identified by the increase and decrease of gas flow at the anode and cathode outlets. This test should be performed at operating conditions (stack temperature > 700°C) and at ambient conditions.

2.3.2 Acceptance criteria

Maximum cross flow leak rate	300	NI/hr
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2.4 Stack insulation

2.4.1 Testing conditions

The stack shall be operated at OCV with a media supply according to 2.1.1 for 10 hours continuously. The stack insulation against the test rig shall be monitored throughout the whole test. Furthermore, the resistance of the insulation gasket shall be measured at the beginning and the end of the test.

2.4.2 Acceptance criteria

No short circuits or voltage drops throughout the test		
Insulation resistance	≥ 50	kΩ

3 Stack stability

3.1 Sulphur tolerance test

3.1.1 Testing conditions

The stack shall be continuously operated at the maximum load point according to 2.1.1 for 48 hours. The anode gas is a synthetic diesel reformat with the composition as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** plus 0.3 ppm H₂S and 0.2 ppm SO₂ (measures should be taken to avoid adsorption of SO₂ at metal surfaces upstream of the stack). The current shall be fixed and the stack voltage shall be monitored.

3.1.2 Acceptance criteria

It is to be expected, that a rapid initial degradation of the stack voltage will be observed, when the sulphur-species are added, followed by a slower degradation after several hours. Acceptance criteria are the overall degradation over the whole test and the degradation rate at the end of the test.

Voltage degradation per cell over the whole test	≤ 0.05	V
Voltage degradation rate per cell over the last 10 test hours	≤ 5 x 10 ⁻⁵	V/h

3.2 Hydrocarbon tolerance test

3.2.1 Testing conditions

The stack shall be ramped up to operating temperature as shown in 2.1.1. After holding the stack at the operating temperature for 10 minutes it should follow the cool down procedure to 450°C, and this temperature should be maintained for 10 minutes. The stack shall be re-heated up to operating temperature in accordance with the procedure shown in 2.1.1. This temperature cycling should be performed with the gas species as shown in Table 1 for 48 hours.

3.2.2 Acceptance criteria

Over time, carbon deposition (mainly Boudouard deposited) may block pores in the anode and cause a reduced voltage. In a worst case scenario carbon may be deposited in sufficient quantities to cause blockages on the anode side. Acceptance criteria are the overall degradation after the test and the degradation rate at the end of the test. Furthermore the back pressure on the anode side should be measured at the test beginning and compared at the test end.

Voltage degradation per cell over the whole test	≤ 0.05	V
Voltage degradation rate per cell for the last 10 test hours	≤ 5 x 10 ⁻⁵	V/h
Stack back pressure increase at end of test	0.5	mbar

3.3 Oxygen tolerance test

3.3.1 Testing conditions

The stack shall be ramped up to and down from the standard operating conditions as defined in 2.1.1. Furthermore, the anode should be in a fully reduced state prior to this test (operation for at least 10 hours with fuel utilisation <60% and current density <0.2A/cm²). The stack shall be operated at > 3750 W with a fuel utilisation of 85 % for a 1 hour period followed, by a 1 hour period at OCV. This procedure should be repeated for 24 hours (12 cycles). The gas species during the test shall be as defined in Table 1. The stack current shall be fixed at the beginning of the test to reach >3750 W and not changed during the test. The stack voltage shall be monitored.

3.3.2 Acceptance criteria

While running at 85% fuel utilisation for a significant duration there is a risk of anode oxidation. Re-oxidation is known to cause stack cell performance degradation, which may be assessed via the voltage. Acceptance criteria are the overall voltage degradation over the whole test and the degradation rate at the end of the test. An increased voltage fluctuation indicates a cracked electrolyte and this is a severe type of damage. The leak rate should also be tested before and after the test in order to identify any sealing damage caused by the anode volume expansion during oxidation.

Voltage degradation per cell over the whole test	≤ 0.01	V
Voltage degradation per cell rate for the last 10 test hours	≤ 5 x 10 ⁻⁵	V/h
Maximum tolerable anode-to-cathode cross leak rate	500	NI/hr

3.4 Thermal cycling test

3.4.1 Testing conditions

The stack shall be ramped up to, and down from, the standard operating conditions as defined in 2.1.1.. This cycle shall be repeated for 48 hours (9 cycles). When above 600°C stack temperature, the gas species should be supplied as defined in 2.1.1 while below 600°C stack temperature no gas should be supplied to the anode while gas supply to the cathode may be used for heat-up and cool-down.

3.4.2 Acceptance criteria

The Thermal cycle test is designed in order to expose a stack's robustness to thermal cycles. Frailty will be exposed as leaks and/or voltage degradation, a consequence of cell internal flaws or increased contact resistances. Voltage instability indicates a cracked electrolyte and this cannot be tolerated.

Voltage degradation per cell over the whole test	≤ 0.01	V
Voltage degradation rate per cell during the last 10 test hours	≤ 5 x 10 ⁻⁵	V/h
Cross leak rate	<400	NI/hr

3.5 High load test

3.5.1 Testing conditions

The stack shall be ramped up to, and down from, the standard operating conditions as defined in 2.1.1. Furthermore, the anode shall be in a fully reduced state prior to this test (operation for at least 10 hours with fuel utilisation <60% and current density <0.2A/cm²). The stack shall be operated at > 3750 W with a fuel utilisation of 85 % for a 48 hour period. The gas species shall be as defined in Table 1. The stack current shall be fixed at the beginning of the test to reach >3750 W and not changed during the test. The stack voltage shall be monitored.

3.5.2 Acceptance criteria

The high load test is designed in order to expose a stack’s frailty to extended operation at high load, which will be exposed as leaks and/or voltage degradation a consequence of cell internal flaws or increased contact resistances. For example, voltage instability may indicate a cracked electrolyte which is not tolerable;

Voltage degradation per cell over the whole test	≤ 0.005	V
Voltage degradation per cell rate for the last 10 test hours	≤ 5 x 10 ⁻⁵	V/h
Cross leak rate	<300	Nl/hr

3.6 APU cycle test

3.6.1 Testing conditions

The stack shall be operated as shown in Figure 2. The gas species shall be as defined in Table 1 and the flow rates will be determined by the defined maximum fuel utilisations. The stack power shall follow the “stack power” as shown in Figure 2. The stack voltage and temperatures at the anode and cathode outlets shall be monitored.

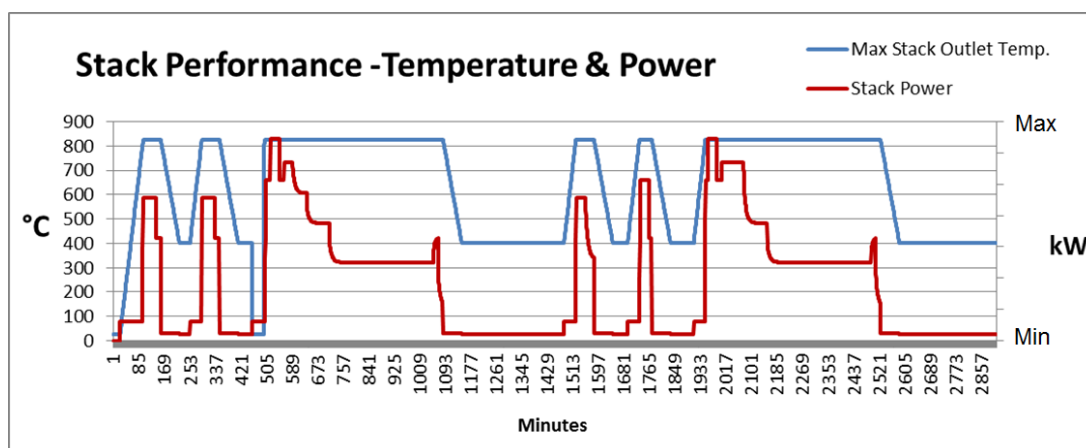


Figure 2: APU cycle test program

3.6.2 Acceptance criteria

The APU load cycle test is designed in order to expose a stack's frailty to load and thermal cycles and the load profile follows a demonstration profile. Failures will be exposed as leaks and/or voltage degradation, a consequence of cell internal flaws or increased contact resistances. Voltage instability indicates a cracked electrolyte and this cannot be tolerated.

Voltage degradation over the whole test	≤ 0.01	V
Cross leak rate	<300	NI/hr

3.7 Shaker test

3.7.1 Testing conditions

A test shall be performed on an appropriate vibration testing apparatus, whereby the stack is fuelled with 95% N₂ and 5% H₂. The test can be performed on a 3D vibration apparatus or the stack mounting direction can be changed to sequentially test all three axes on 1D testing device.

During the test the stack has to be at operating temperature. In a first step, a frequency scan (from 0-300 Hz at a sweep rate of 10Hz/min) should be performed to identify resonant frequencies (and their harmonics) of the mounted stack. In a second step, a stepwise increase of frequencies at defined accelerations (to be performed for all 3 stack axes) should be performed as follows:

Accelerations	1g	3g	5g	8g	10g
Frequency	3, 175, 300 Hz	3, 175, 300 Hz	3, 175, 300 Hz	3, 175, 300 Hz	3, 175, 300 Hz

In the third step, a random (white) noise test should be performed with a a signal between 1-10g acceleration and at 1-300Hz frequency (symmetric average around 3g and at 100Hz). This test should be performed for at least 48hrs.

Prior to and after the shaker test, a stack performance test (defined under 2.2.1) should be performed to compare the performance before- and after all 3 vibration tests.

3.7.2 Acceptance criteria

The shaker test is designed in order to expose stack's robustness to vibration and shock. Principally no Eigen frequencies (and harmonics thereof) should be recorded during the vibration scan.

Number of resonant frequencies between 0 – 300 Hz	0	#
Voltage degradation per cell over the whole test	≤ 0.01	V
Cross leak rate	<300	NI/hr