AIR LIQUIDE ADVANCED TECHNOLOGIES	**PROCES-VERBAL D'ESSAI** ***TEST REPORT*** **CRYOGENIC TURBO EXPANDER**	**N° : C4058-NT-22 (1)** Folio : 1 / 11

AFFAIRE : **RHEA** *JOB* :	N° : 301 0914 *N° :*	Fiche Suiveuse n° : *Inspection traveller n° :*
Identification du matériel : **C7 511 HF_1** N° : T1 *Material identification* :	Quantité / *Quantity* : 1 Lot / *Batch* :	

Fournisseur/Fabricant : *Supplier / Manufacturer :* **AIR LIQUIDE**	Organisme de Contrôle : *Inspected by :* **DTEC**	Lieu : *Location :* **Sassenage**	Phase : *Phase :*

Documents de référence : *Reference documents :* PROCEDURE : **D4444-PO-2**	Instruments de contrôles utilisés : *Inspection instruments used :*	
	Type / *Type*	N° de Gestion/*Control n°*
	Test bed	**504 9999 100**

MESURES	**RESULTATS**	**OBSERVATIONS**
PIVOTERIE / *BEARINGS*	Pass	
VITESSES CRITIQUES *Critical speeds*	Pass	
SURVITESSE / *Overspeeds*	Pass	
DESCENTE EN FROID *Cold down*	Pass	
RENDEMENT / *Efficiency*	Pass	Limited by our test bench

DECISION : *DECISION :* **CONFORME** / *PASS* ☑ **NON CONFORME** / *FAIL* ☐	**OBSERVATIONS :** *COMMENTS :*

	ESSAI / *TEST*	**Responsable / *Manager***	**A.Q. / *Q.A.***		
NOM / *NAME*	R-Guimaraes	F. Delcayre			
DATE / *DATE*	30/11/2013	30/11/2013			
SIGNATURE / *VISA*					

CONTENTS

1. SCOPE

This report is a summary of the tests of a Cryogenic turbo-expander cartridge, performed on DTA test bed according to the procedure D4444-PO-2.

2. PROCESS CONDITION

The data sheet in appendix gives the turbine process conditions specified by the customer.

3. GAS USED FOR THE TEST

☑Helium ☐Nitrogen

4. BEARING CONDITIONS

The diagrams in appendix give the gas bearing conditions :

- to be applied on site,

- to be applied during the test.

5. ANNEXES

TESTS REPORTS

TEST REPORT

5.1 THRUST BEARING TEST, LOW SPEED

(Items 6.1 of procedure)

Cartridge number: C7 511 HF_1
Bearing conditions required: NORMAL

CASE	EXTREME 1	EXTREME 2	
INPUTS			
Load	23	1310	N
On	Brake	Turbine	Bearing
Equivalent pressure difference on the shaft	0	20	10^5Pa
OUTPUTS			
Inlet bearing pressure	17.88	17.85	10^5Pa
Outlet bearing pressure	1.98	1.98	10^5Pa
Turbine outlet pressure (1)	2.07	2.05	10^5Pa
Brake pressure (2)	1.99	17.46	10^5Pa
Pressure difference = (2) – (1)	-0.08	15.41	10^5Pa
Speed	7	3	H_Z
Passed/failed	passed	passed	

TEST REPORT

5.2 THRUST AND JOURNAL BEARINGS TEST, HIGH SPEED

(Items 6.2 of procedure)

Cartridge number: C7 511 HF_1
Bearing conditions required: NORMAL

MODE	MINIMAL	NOMINAL	MAXIMAL	
INPUTS				
Turbine outlet design pressure (1)	14.1	12.4	9.6	10^5Pa
Brake design pressure (2)	11.2	14	16.8	10^5Pa
Δ = 2-1	-2.9	1.6	7.2	10^5Pa
OUTPUTS				
Inlet bearing pressure		18.96	18.99	10^5Pa
Outlet bearing pressure		1.72	1.68	10^5Pa
Turbine outlet test pressure (1)		3.28	3.51	10^5Pa
Brake test pressure (2)		4.87	10.65	10^5Pa
Δ = (2) – (1)		1.59	7.14	10^5Pa
Speed		1031	762	Hz
Passed/failed		Passed	passed	

TEST REPORT

5.3 THRUST AND JOURNAL BEARING TEST, HIGH SPEED

(Items 6.2 of procedure)

Cartridge number: C7 511 HF_1
Bearing conditions required: ALARM AND STOP

BEARING CONDITIONS	**ALARM**	**STOP**	
Mode	Nominal	Nominal	
INPUTS			
Turbine design outlet pressure (1)	12.4	12.4	10^5Pa
Brake design pressure (2)	14	14	10^5Pa
Δ = 2-1	-1.6	-1.6	10^5Pa
OUTPUTS			
Inlet bearing pressure		18.97	10^5Pa
Outlet bearing pressure		1.72	10^5Pa
Turbine outlet test pressure		2.25	10^5Pa
Brake outlet pressure		2.82	10^5Pa
Δ = 2-1		0.57	10^5Pa
Speed		1082	Hz
Passed/failed		passed	

TEST REPORT

5.4 CRITICAL SPEEDS AND SHAFT VIBRATIONS

(Items 6.3 of procedure)

Cartridge number: C7 511 HF_1
Bearing conditions required: STOP

INPUTS					
	1st RIGID MODE		2nd RIGID MODE		
Calculated peak freq.	650		750		H_z
OUTPUTS					
Measured critical speeds	BEGIN.	END	BEGIN.	END	
	550			650	H_z
Sound level estimation	B		B		
Time within the mode (> 3 ‘)					Min
Inlet bearing pressure	19.01		19.01		10^5Pa
Outlet bearing pressure	1.61		1.61		10^5Pa
Passed/failed	passed		passed		

Sound level estimation:

A: Inaudible B: Perceptible C: Noisy D: Excessive

TEST REPORT

5.5 OVERSPEED TEST

(Items 6.4 of procedure)

Cartridge number: C7 511 HF_1
Bearing conditions required: NORMAL

INPUTS		
Nominal speed (Hz)	Maximum speed (Hz)	Over speed (Hz)
1060	1130	1140
OUPUTS		

BEARING TEST CONDITIONS

BEARING GAS PRESSURE (10^5Pa)		BEARING GAS TEMPERATURE (°C)		BEARING GAS FLOW RATE (g/s)
SUPPLY	RETURN	SUPPLY	RETURN	
18.94	1.74	15.9	18.2	31.32

TURBINE TEST CONDITIONS

TURBINE PRESSURE (10^5Pa)		TURBINE TEMPERATURE (K)		TURBINE FLOW RATE (g/s)
SUPPLY	RETURN	SUPPLY	RETURN	
8.13	2.45	234.99	189.29	165.98

BRAKE TEST CONDITIONS

INLET BRAKE PRESSURE 10^5 Pa	OUTLET BRAKE TEMPERATURE °C
3	60.3

TEST RESULTS

ROTATION SPEED H_z	STEADY STATE	OVERSPEED STATE DURATION (mn)	COMMENTS	
			FAIL	PASS
1145	A	3		X

Steady state evaluation:

A: Stable B: Noisy C: Unstable

TEST REPORT

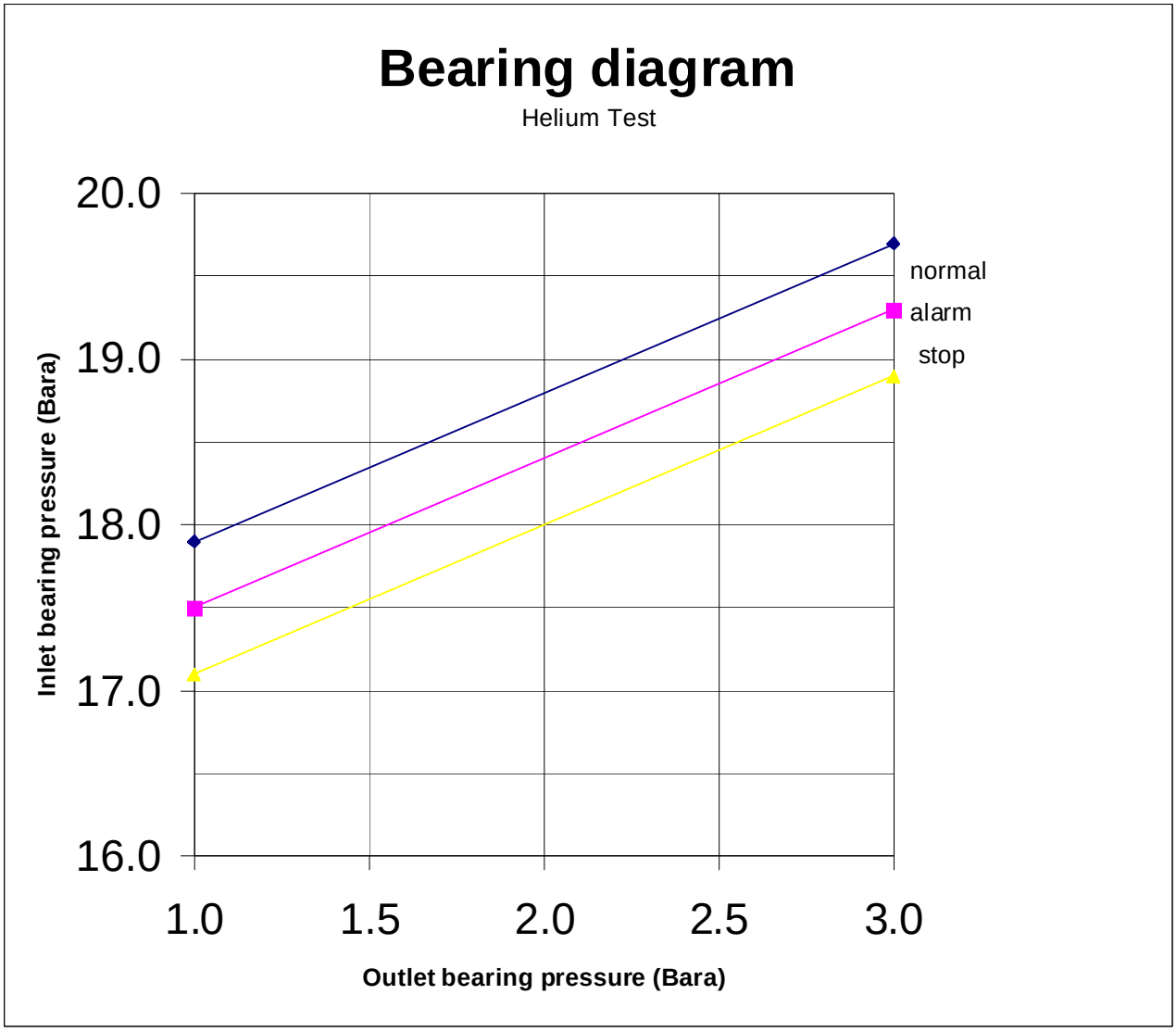
5.6 COOL DOWN, START-UP AND SHUT-DOWN

(Items 6.5 and 6.6 of procedure)

Cartridge number: C7 511 HF_1
Bearing conditions required: normal
Nominal speed:

	AMBIENT	MEDIUM	+10% K	NOMINAL	- 10%	
Target outlet temperature	250	240	225	206	185	K
TURBINE :						
Inlet pressure	4.11	4.39	5.74	7.49	6.64	10^5Pa
Outlet pressure	2.28	2.23	2.18	2.34	2.28	10^5Pa
Inlet temperature	243.37	243.79	244.89	248.32	224.75	K
Outlet temperature	241.57	235.42	218.57	205.83	185.23	K
Flow (Ø distrib. 70% nominal)	108.99	121.88	114.69	148.92	142.36	g/s
U1/C0	0.28	0.28	0.30	0.33	0.35	
µ	3.79	14.03	34.24	46.08	50.93	%
BRAKE :						
Inlet pressure	2.75	2.61	2.78	2.92	2.77	10^5Pa
Outlet temperature	19.7	20.9	26	31.6	65	°C
BEARING :						
Inlet pressure	19.01	18.99	18.97	18.96	18.95	10^5Pa
Outlet pressure	1.61	1.62	1.66	1.71	1.71	10^5Pa
Inlet temperature	15.8	15.8	15.8	15.8	15.9	°C
Outlet temperature	18.7	18.7	18.6	18.6	17.5	°C
Inlet flow	28.21	28.52	29.47	30.80	30.72	g/s
SPEED :	686	686	916	1084		Hz
Number of start up/shut down					3	
Fail/pass	passed	passed	passed	passed	passed	

AIR LIQUIDE ADVANCED TECHNOLOGIES	**DIAGRAMME PIVOTERIE** ***GAS BEARING DIAGRAM***	**N° : C4058-NT-22 (0)** Folio : 10 / 11
AFFAIRE / *JOB* : RHEA	N° : T1	
Identification du matériel / *Material identification* : C7 511 HF_1		
APPLICATION : ☑ Site Client/*Customer* ☑ ALAT Test		



TEST REPORT

5.7 EFFICIENCY VERSUS U1/CO

(Items 6.7 of procedure)
Cartridge number: C7 511 HF_1

INPUTS **TURBINE PROCESS CONDITIONS (12.5Bar 735W/37Lh w LN2)**

GAS	PRESSURES 10^5Pa		TEMPERATURES K		FLOW kg/s 10^{-3}	ENTHALP. DROP kJ/kg		η	ROTATION SPEED Hz	REFRIG. POWER Watt	INLET WHEEL PRESS. 10^5Pa
	INLET	OUTLET	INLET	OUTLET		Δ Hs	Δ Hr	Δ Hr/ Δ Hs			
He	19.6	12.41	234.4	205.6	1166	205.5	152.09	0.74	1060	177333	15.17

OUTPUTS **TURBINE TEST CONDITIONS**

GAS	PRESSURES 10^5Pa		TEMPERATURES K		FLOW kg/s 10^{-3}	ENTHALP. DROP KJ/kg		η	ROTATION SPEED Hz	REFRIG. POWER Watt	INLET WHEEL PRESS. 10^5Pa
	INLET	OUTLET	INLET	OUTLET		Δ Hs	Δ Hr	Δ Hr/ Δ Hs			
He	7.49	2.34	248.3	205.83	148.92	482.5	222.3	0.46	1084	33111	3.02

BEARING TEST CONDITIONS

GAS	PRESSURES 10^5Pa		TEMPERATURES °C	
	INLET	OUTLET	INLET	OUTLET
He	18.96	1.71	15.8	18.6

BRAKE TEST CONDITIONS

GAS	PRESSURES 10^5Pa		TEMPERATURES °C	
	INLET	OUTLET	INLET	OUTLET
He	2.92	3.33	19	31.6

TEST RESULTS

WHEEL DIAM. mm	TIP VELOCITY U_1 m/s	SPOUTING VELOCITY C_O m/s	U_1/ Co	η %	COMMENTS	
					FAIL	PASS
94.0	320.11	982.3	0.325	46.08		X

UTILITY FLOW RATE

GAS BEARING SUPPLY g / s	BRAKE SUPPLY g / s	SEAL GAS g / s	RETURN g / s
30.80	0.22	0.18	35.11