AIR LIQUIDE ADVANCED TECHNOLOGIES	**PROCES-VERBAL D'ESSAI** ***TEST REPORT*** **CRYOGENIC TURBO EXPANDER**	**N° : C4058-NT-16 (1)** Folio : 1 / 11

AFFAIRE : **RHEA** *JOB* :	N° : 301 0914 *N° :*	Fiche Suiveuse n° : *Inspection traveller n° :*
Identification du matériel : **C7 509 HG_1** N° : 324-XT002 *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***	L. Pelosi B. Renzetti	F. Delcayre			
DATE / ***DATE***	19 07 2013	19 07 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 509 HG_1
Bearing conditions required: NORMAL

CASE	EXTREME 1	EXTREME 2	
INPUTS			
Load	0	1233	N
On	Brake	Turbine	Bearing
Equivalent pressure difference on the shaft	0	19	10^5Pa
OUTPUTS			
Inlet bearing pressure	18.05	18.00	10^5Pa
Outlet bearing pressure	1.98	2.01	10^5Pa
Turbine outlet pressure (1)	2.08	2.08	10^5Pa
Brake pressure (2)	2.13	17.59	10^5Pa
Pressure difference = (2) – (1)	.05	15.31	10^5Pa
Speed	4	>0	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 509 HG_1
Bearing conditions required: NORMAL

MODE	MINIMAL	NOMINAL	MAXIMAL	
INPUTS				
Turbine outlet design pressure (1)	5.7	4.9	3.5	10^5Pa
Brake design pressure (2)	11.2	14	16.8	10^5Pa
Δ = 2-1	5.5	9.1	13.3	10^5Pa
OUTPUTS				
Inlet bearing pressure	17.90	17.86		10^5Pa
Outlet bearing pressure	2.32	2.71		10^5Pa
Turbine outlet test pressure (1)	2.7	3.18		10^5Pa
Brake test pressure (2)	8.1	12.38		10^5Pa
Δ = (2) – (1)	5.4	9.2		10^5Pa
Speed	711	630		Hz
Passed/failed	passed	passed		

TEST REPORT

5.3 THRUST AND JOURNAL BEARING TEST, HIGH SPEED

(Items 6.2 of procedure)

Cartridge number: C7 509 HG_1
Bearing conditions required: ALARM AND STOP

BEARING CONDITIONS	**ALARM**	**STOP**	
Mode	Nominal	Nominal	
INPUTS			
Turbine design outlet pressure (1)	4.9	4.9	10^5Pa
Brake design pressure (2)	14	14	10^5Pa
Δ = 2-1	9.1	9.1	10^5Pa
OUTPUTS			
Inlet bearing pressure		18.0	10^5Pa
Outlet bearing pressure		2.35	10^5Pa
Turbine outlet test pressure		2.57	10^5Pa
Brake outlet pressure		3.2	10^5Pa
Δ = 2-1		1.37	10^5Pa
Speed		959	Hz
Passed/failed		passed	

TEST REPORT

5.4 CRITICAL SPEEDS AND SHAFT VIBRATIONS

(Items 6.3 of procedure)

Cartridge number: C7 509 HG_1
Bearing conditions required: STOP

INPUTS					
	1^{st} RIGID MODE		2^{nd} RIGID MODE		
Calculated peak freq.	650		750		H_z
OUTPUTS					
Measured critical speeds	BEGIN.	END	BEGIN.	END	
	600			750	H_z
Sound level estimation	B		B		
Time within the mode (> 3 ‘)					Min
Inlet bearing pressure	19.0		19.0		10^5Pa
Outlet bearing pressure	1.5		1.5		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 509 HG_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	
18.96	1.51	17.0	22.4	39.8

TURBINE TEST CONDITIONS

TURBINE PRESSURE (10^5Pa)		TURBINE TEMPERATURE (K)		TURBINE FLOW RATE (g/s)
SUPPLY	RETURN	SUPPLY	RETURN	
10.20	2.91	285.7	230.3	197.1

BRAKE TEST CONDITIONS

INLET BRAKE PRESSURE 10^5 Pa	OUTLET BRAKE TEMPERATURE °C
3.38	33.0

TEST RESULTS

ROTATION SPEED H_z	STEADY STATE	OVERSPEED STATE DURATION (mn)	COMMENTS	
			FAIL	PASS
1204	A	3		X

Steady state evaluation:

A: Stable B: Noisy C: Unstable

TEST REPORT

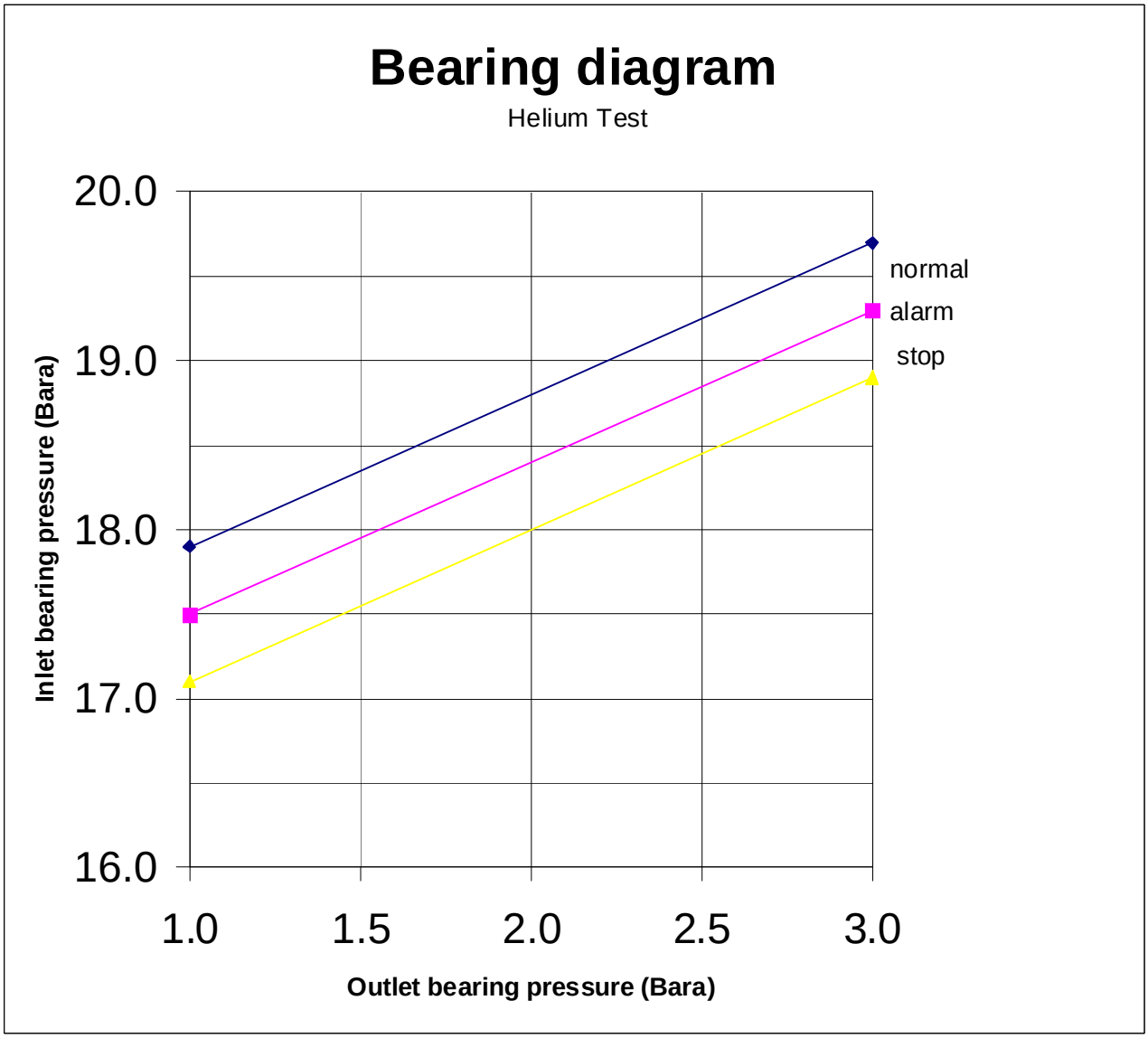
5.6 COOL DOWN, START-UP AND SHUT-DOWN

(Items 6.5 and 6.6 of procedure)

Cartridge number: C7 509 HG_1
Bearing conditions required: normal
Nominal speed:

	AMBIENT	MEDIUM	+10% K	NOMINAL	- 10%	
Target outlet temperature	250	240	110	99	90	K
TURBINE :						
Inlet pressure		6.70	6.59	5.99		10^5Pa
Outlet pressure		2.48	2.72	2.56		10^5Pa
Inlet temperature		262.43	133.2	119.51		K
Outlet temperature		218.80	110.4	99.42		K
Flow		133.07	176.7	168.4		g/s
U1/C0		0.29	0.41	0.43		
µ		50.8	57.6	58.5		%
BRAKE :						
Inlet pressure		3.4	3.2	2.86		10^5Pa
Outlet temperature		33.6	49.3	46.9		°C
BEARING :						
Inlet pressure		17.82	17.92	18.2		10^5Pa
Outlet pressure		2.25	2.54	2.4		10^5Pa
Inlet temperature		18.0	17.2	17.1		°C
Outlet temperature		19.1	16.6	16.7		°C
Inlet flow		32.8	32.06	32.3		g/s
SPEED :		921	891	871		Hz
Number of start up/shut down					3	
Fail/pass		passed	passed	passed	passed	

AIR LIQUIDE ADVANCED TECHNOLOGIES	**DIAGRAMME PIVOTERIE** ***GAS BEARING DIAGRAM***	**N° : C4058-NT-16 (0)** Folio : 10 / 11
AFFAIRE / *JOB* : RHEA	N° : 301 0914	
Identification du matériel / *Material identification* : C7 509 HG_1		
APPLICATION : ☑ Site Client/*Customer* ☑ ALAT Test		



TEST REPORT

5.7 EFFICIENCY VERSUS U1/CO

(Items 6.7 of procedure)
Cartridge number: C7 509 HG_1

INPUTS **TURBINE PROCESS 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	12.16	4.87	128.2	99.3	1166	206.3	152.7	0.74	1060	178026	7.35

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	5.89	2.56	118.0	97.8	164.7	175.4	106.1	.605	889	17467	3.13

BEARING TEST CONDITIONS

GAS	PRESSURES 10^5Pa		TEMPERATURES °C	
	INLET	OUTLET	INLET	OUTLET
He	17.91	2.42	17.1	16.5

BRAKE TEST CONDITIONS

GAS	PRESSURES 10^5Pa		TEMPERATURES °C	
	INLET	OUTLET	INLET	OUTLET
He	2.69	2.91	30.3	46.5

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	263	591	0.44	60.5		X

UTILITY FLOW RATE

GAS BEARING SUPPLY g / s	BRAKE SUPPLY g / s	SEAL GAS g / s	RETURN g / s
32.0	0.19	0.11	35.23