| AIR LIQUIDE ADVANCED TECHNOLOGIES | **PROCES-VERBAL D'ESSAI**<br>***TEST REPORT***<br>**CRYOGENIC TURBO EXPANDER** | **N° : C4058-NT- 28 (0)**<br>Folio : 1 / 11 |
|---|---|---|

| | | |
|---|---|---|
| AFFAIRE : **RHEA**<br>*JOB* : | N° : 301 0914<br>*N° :* | Fiche Suiveuse n° :<br>*Inspection traveller n° :* |
| Identification du matériel : **C7 513 $HL_1$** N° : 322XT001<br>*Material identification* : | Quantité / *Quantity* : 1<br>Lot / *Batch* : | |

| | | | |
|---|---|---|---|
| Fournisseur/Fabricant :<br>*Supplier / Manufacturer :*<br>**AIR LIQUIDE** | Organisme de Contrôle :<br>*Inspected by :*<br>**D2TI** | Lieu :<br>*Location :*<br>**Sassenage** | Phase :<br>*Phase :* |

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

| **MESURES** | **RESULTATS** | **OBSERVATIONS** |
|---|---|---|
| PIVOTERIE / *BEARINGS* | Pass | |
| VITESSES CRITIQUES<br>*Critical speeds* | Pass | |
| SURVITESSE / *Overspeeds* | Pass | |
| DESCENTE EN FROID<br>*Cold down* | Pass | |
| RENDEMENT / *Efficiency* | Pass | |

| | |
|---|---|
| **DECISION** :<br>*DECISION :*<br>**CONFORME** / *PASS* ☑<br>**NON CONFORME** / *FAIL* ☐ | **OBSERVATIONS :**<br>*COMMENTS :* |

| | **ESSAI / *TEST*** | **Responsable / *Manager*** | **A.Q. / *Q.A.*** | | |
|---|---|---|---|---|---|
| **NOM / *NAME*** | L. Pelosi | F. Delcayre | | | |
| **DATE / *DATE*** | 17 01 2012 | 18 01 2012 | | | |
| **SIGNATURE / *VISA*** |  |  | | | |

# CONTENTS

**1. SCOPE ..... 3**

**2. PROCESS CONDITION ..... 3**

**3. GAS USED FOR THE TEST ..... 3**

**4. BEARING CONDITIONS ..... 3**

**5. ANNEXES ..... 3**

5.1 THRUST BEARING TEST, LOW SPEED ..... 4
5.2 THRUST AND JOURNAL BEARINGS TEST, HIGHT SPEED ..... 5
5.3 THRUST AND JOURNAL BEARING TEST,HIGH SPEED ..... 6
5.4 CRITICAL SPEEDS AND SHAFT VIBRATIONS ..... 7
5.5 OVERSPEED TEST ..... 8
5.6 COOL DOWN, START-UP AND SHUT-DOWN ..... 9
5.7 EFFICIENCY VERSUS U1/CO ..... 11

# 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

## 5.1 THRUST BEARING TEST, LOW SPEED

(Items 6.1 of procedure)

Cartridge number: C7 513 $HL_1$
Bearing conditions required: NORMAL

| CASE | EXTREME 1 | EXTREME 2 | |
|---|---|---|---|
| INPUTS | | | |
| Load | 0 | 900 | N |
| On | Brake | Turbine | Bearing |
| Equivalent pressure difference on the shaft | 0 | 14 | $10^5$Pa |
| OUTPUTS | | | |
| Inlet bearing pressure | 9.13 | 9.21 | $10^5$Pa |
| Outlet bearing pressure | 1.73 | 1.7 | $10^5$Pa |
| Turbine outlet pressure (1) | 2.41 | 1.73 | $10^5$Pa |
| Brake pressure (2) | 2.40 | 14.24 | $10^5$Pa |
| Pressure difference = (2) – (1) | -0.01 | 12.51 | $10^5$Pa |
| Speed | 9 | >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 513 $HL_1$
Bearing conditions required: NORMAL

| MODE | MINIMAL | NOMINAL | MAXIMAL | |
|---|---|---|---|---|
| INPUTS | | | | |
| Turbine outlet design pressure (1) | 3.0 | 1.9 | 1.3 | $10^5$Pa |
| Brake design pressure (2) | 5.6 | 7.0 | 8.4 | $10^5$Pa |
| $\Delta$ = 2-1 | 2.6 | 5.1 | 7.1 | $10^5$Pa |
| OUTPUTS | | | | |
| Inlet bearing pressure | 9.17 | 9.17 | 9.18 | $10^5$Pa |
| Outlet bearing pressure | 1.8 | 1.72 | 1.73 | $10^5$Pa |
| Turbine outlet test pressure (1) | 3.06 | 3.14 | 3.12 | $10^5$Pa |
| Brake test pressure (2) | 5.11 | 8.3 | 9.2 | $10^5$Pa |
| $\Delta$ = (2) – (1) | 2.05 | 5.16 | 6.08 | $10^5$Pa |
| Speed | 554 | 461 | 436 | Hz |
| Passed/failed | passed | passed | passed | |

**TEST REPORT**

## 5.3 THRUST AND JOURNAL BEARING TEST, HIGH SPEED

(Items 6.2 of procedure)

Cartridge number: C7 513 $HL_1$
Bearing conditions required: ALARM AND STOP

| **BEARING CONDITIONS** | **ALARM** | **STOP** | |
|---|---|---|---|
| Mode | Nominal | Nominal | |
| INPUTS | | | |
| Turbine design outlet pressure (1) | 1.9 | 1.9 | $10^5$Pa |
| Brake design pressure (2) | 7.0 | 7.0 | $10^5$Pa |
| $\Delta$ = 2-1 | 5.1 | 5.1 | $10^5$Pa |
| OUTPUTS | | | |
| Inlet bearing pressure | | 8.5 | $10^5$Pa |
| Outlet bearing pressure | | 1.78 | $10^5$Pa |
| Turbine outlet test pressure | | 3.08 | $10^5$Pa |
| Brake outlet pressure | | 4.39 | $10^5$Pa |
| $\Delta$ = 2-1 | | 1.31 | $10^5$Pa |
| Speed | | 595 | Hz |
| Passed/failed | | passed | |

**TEST REPORT**

## 5.4 CRITICAL SPEEDS AND SHAFT VIBRATIONS

(Items 6.3 of procedure)

Cartridge number: C7 513 $HL_1$
Bearing conditions required: STOP

| INPUTS | | | | | |
|---|---|---|---|---|---|
| | 1st RIGID MODE | | 2nd RIGID MODE | | |
| Calculated peak freq. | 340 | | 490 | | $H_z$ |
| OUTPUTS | | | | | |
| Measured critical speeds | BEGIN. | END | BEGIN. | END | |
| | | | | 350 | $H_z$ |
| Sound level estimation | A | | B | | |
| Time within the mode (> 3 ‘) | | | | | Min |
| Inlet bearing pressure | 9.2 | | 9.2 | | $10^5$Pa |
| Outlet bearing pressure | 1.69 | | 1.69 | | $10^5$Pa |
| 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 513 $HL_1$
Bearing conditions required: NORMAL

| INPUTS | | |
|---|---|---|
| Nominal speed (Hz) | Maximum speed (Hz) | Over speed (Hz) |
| 620 | 680 | 700 |
| OUPUTS | | |

**BEARING TEST CONDITIONS**

| BEARING GAS PRESSURE ($10^5$Pa) | | BEARING GAS TEMPERATURE (°C) | | BEARING GAS FLOW RATE (g/s) |
|---|---|---|---|---|
| SUPPLY | RETURN | SUPPLY | RETURN | |
| 9.15 | 1.77 | 18.2 | 20.5 | 39.65 |

**TURBINE TEST CONDITIONS**

| TURBINE PRESSURE ($10^5$Pa) | | TURBINE TEMPERATURE (K) | | TURBINE FLOW RATE (g/s) |
|---|---|---|---|---|
| SUPPLY | RETURN | SUPPLY | RETURN | |
| 8.64 | 3.09 | 201.07 | 160.13 | 947.5 |

**BRAKE TEST CONDITIONS**

| INLET BRAKE PRESSURE $10^5$ Pa | OUTLET BRAKE TEMPERATURE °C |
|---|---|
| 3.1 | 69.9 |

**TEST RESULTS**

| ROTATION SPEED $H_z$ | STEADY STATE | OVERSPEED STATE DURATION (mn) | COMMENTS | |
|---|---|---|---|---|
| | | | FAIL | PASS |
| 693 | A | 3 | | X |

Steady state evaluation

A: Stable B: Noisy C: Unstable

**TEST REPORT**

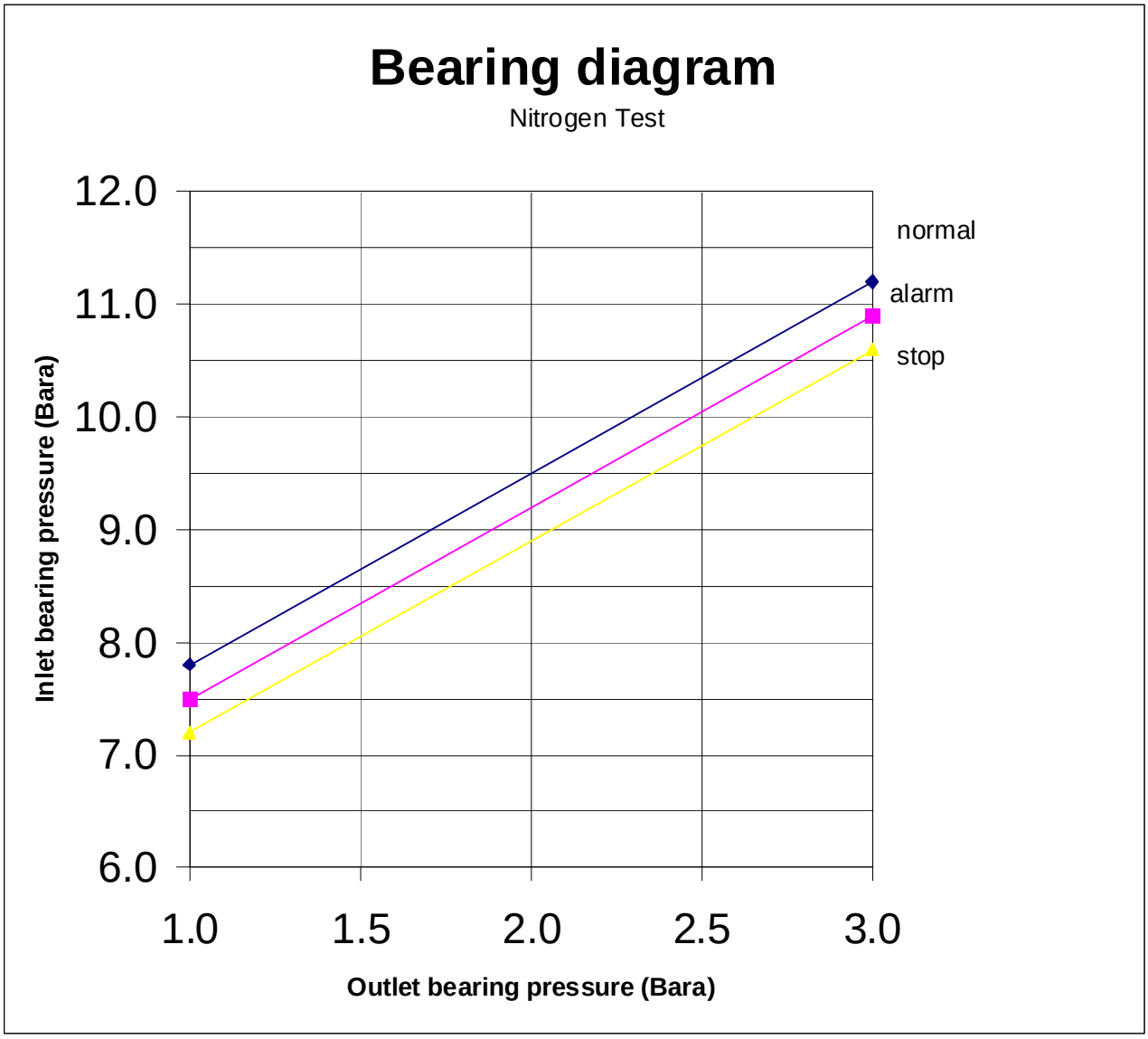
## 5.6 COOL DOWN, START-UP AND SHUT-DOWN

(Items 6.5 and 6.6 of procedure)

Cartridge number: C7 513 $HL_1$
Bearing conditions required: normal
Nominal speed:

| | AMBIENT | MEDIUM | +10% K | NOMINAL | - 10% | |
|---|---|---|---|---|---|---|
| Target outlet temperature | 250 | 150 | 110 | 100 | 90 | K |
| **TURBINE :** | | | | | | |
| Inlet pressure | 6.79 | 8.29 | 8.12 | 8.13 | 8.15 | $10^5$Pa |
| Outlet pressure | 2.71 | 3.02 | 3.12 | 3.13 | 3.22 | $10^5$Pa |
| Inlet temperature | | 173.69 | 136.25 | 124.93 | 120.35 | K |
| Outlet temperature | | 142.88 | 110.03 | 100.0 | 96.95 | K |
| Flow | 671.1 | 991.2 | 1114.0 | 1166.6 | 1203.8 | g/s |
| U1/C0 | 0.43 | 0.52 | 0.57 | 0.59 | 0.61 | |
| µ | | 67.06 | 74.62 | 76.69 | 75.62 | % |
| **BRAKE :** | | | | | | |
| Inlet pressure | 3.16 | 4.43 | 4.67 | 4.57 | 4.57 | $10^5$Pa |
| Outlet temperature | 40.6 | 58.5 | 59.0 | 57.9 | 57.3 | °C |
| **BEARING :** | | | | | | |
| Inlet pressure | 9.12 | 9.13 | 9.11 | 9.12 | 9.12 | $10^5$Pa |
| Outlet pressure | 1.76 | 1.66 | 1.75 | 1.73 | 1.84 | $10^5$Pa |
| Inlet temperature | 17.2 | 18.5 | 18.6 | 18.6 | 18.6 | °C |
| Outlet temperature | 20.8 | 18.0 | 15.9 | 14.3 | 13.7 | °C |
| Inlet flow | 39.2 | 38.27 | 37.8 | 37.65 | 37.38 | g/s |
| **SPEED :** | 602 | 991.2 | 533 | 529 | 522 | Hz |
| Number of start up/shut down | 3 | | | | 3 | |
| Fail/pass | passed | passed | passed | passed | passed | |

| AIR LIQUIDE ADVANCED TECHNOLOGIES | **DIAGRAMME PIVOTERIE**<br>***GAS BEARING DIAGRAM*** | **N° : C4058-NT- (0)**<br>Folio : 10 / 11 |
|---|---|---|
| AFFAIRE / *JOB* : RHEA | N° : 301 0914 | |
| Identification du matériel / *Material identification* : C7 513 $HL_1$ | | |
| APPLICATION : ☑ Site Client/*Customer* ☑ ALAT Test | | |



**TEST REPORT**

## 5.7 EFFICIENCY VERSUS U1/CO

(Items 6.7 of procedure)
Cartridge number: C7 513 $HL_1$

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

| GAS | PRESSURES $10^5$Pa | | TEMPERATURES K | | FLOW kg/s $10^{-3}$ | ENTHALP. DROP kJ/kg | | $\eta$ | ROTATION SPEED Hz | REFRIG. POWER Watt | INLET WHEEL PRESS. $10^5$Pa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | INLET | OUTLET | INLET | OUTLET | | $\Delta$ Hs | $\Delta$ Hr | $\Delta$ Hr/ $\Delta$ Hs | | | |
| N2 | 5.53 | 1.86 | 127 | 99.8 | 743 | 34.4 | 26.2 | 0.76 | 620 | 19451 | 3.23 |

**OUTPUTS** **TURBINE TEST CONDITIONS**

| GAS | PRESSURES $10^5$Pa | | TEMPERATURES K | | FLOW kg/s $10^{-3}$ | ENTHALP. DROP KJ/kg | | $\eta$ | ROTATION SPEED Hz | REFRIG. POWER Watt | INLET WHEEL PRESS. $10^5$Pa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | INLET | OUTLET | INLET | OUTLET | | $\Delta$ Hs | $\Delta$ Hr | $\Delta$ Hr/ $\Delta$ Hs | | | |
| N2 | 8.09 | 3.12 | 124.59 | 99.77 | 1169.1 | 28.16 | 21.59 | 0.77 | 527 | 25239 | 4.99 |

**BEARING TEST CONDITIONS**

| GAS | PRESSURES $10^5$Pa | | TEMPERATURES °C | |
|---|---|---|---|---|
| | INLET | OUTLET | INLET | OUTLET |
| N2 | 9.11 | 1.72 | 18.6 | 14.2 |

**BRAKE TEST CONDITIONS**

| GAS | PRESSURES $10^5$Pa | | TEMPERATURES °C | |
|---|---|---|---|---|
| | INLET | OUTLET | INLET | OUTLET |
| N2 | 4.57 | | | 57.8 |

**TEST RESULTS**

| WHEEL DIAM. mm | TIP VELOCITY $U_1$ m/s | SPOUTING VELOCITY $C_O$ m/s | $U_1$/ Co | $\eta$ % | COMMENTS | |
|---|---|---|---|---|---|---|
| | | | | | FAIL | PASS |
| 85.0 | 140.65 | 237.3 | 0.6 | 76.66 | | X |

**UTILITY FLOW RATE**

| GAS BEARING SUPPLY g / s | BRAKE SUPPLY g / s | SEAL GAS g / s | RETURN g / s |
|---|---|---|---|
| 37.66 | 4.57 | 1.68 | 42.87 |