Test Report No.:	*FS 28710121*
Version-No.:	*3*
Date:	*2011-07-20*
Subsystem:	*Pneumatic and Hydraulic Single and Double Acting Actuator*
Model:	*RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO (including option Q=Quick, fast running actuator)*
Customer:	***Rotork Sweden AB*** *P.O. Box 80* *SE-79122 Falun*
Order No. / Date:	*Rotork Order dated 2010-06-07*
Test Specifications:	*IEC 61508: 2010 Part 1÷7* *Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems*
Test Institute:	***TÜV Rheinland Italia S.r.l.*** *Via Mattei, 10* *20010 Pogliano Milanese (MI)*
Department:	***TÜV Rheinland Italia S.r.l.*** *Test Laboratory for Pressure Equipment* *Via Italia, 1* *24030 Medolago (BG)*
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This document is only valid in its entirety and separation of any part is not allowed.

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PFD CALCULATION REPORT OF ROTORK PNEUMATIC AND HYDRAULIC SINGLE AND DOUBLE ACTING ACTUATORS SERIES RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO

1 PURPOSE AND SCOPE

This report summarizes the results of a PFD evaluation of the Rotork Sweden Pneumatic and Hydraulic Single and Double Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO.

A PFD evaluation was performed, according to IEC 61508-2, to evaluate the λ values and, consequently, the SFF and the PFD_{AVG} values of the Rotork Sweden Pneumatic Actuator, Single Acting.

The PFD evaluation according to IEC 61508-2 is only one of the steps to be taken to achieve functional safety certification according to IEC 61508 of a device. Failure rates and Safe Failure Fraction are determined.
For full functional safety certification purposes all the requirements of IEC 61508 (Part 1÷7), including the Functional Safety Management System and the Safety LifeCycle Management (with reference to parts 6 and 7 of IEC 61508-1, with application to the product subject of the Certification) must be considered.

2 DESCRIPTION OF SYSTEM

2.1 Scope of calculation/types

This report is related to the following Rotork Sweden Actuator:

- Pneumatic and Hydraulic Scotch-Yoke Single and Double Acting Actuators Series RC (RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO)

Legenda (after the first two letters):
O: Overstroke
T: Extracorrosion
C: Carbon Steel
I: dimension in inch (only for external connection)
(including option Q=Quick, fast running actuator)
RCE is the denomination for bare actuators used for our own complete hydraulic units (with motor, pump, tank and so on). Exactly as a RC hydraulic but with fastenings for the hydraulic unit.

The aforementioned differences have no effect on PFD calculations.

Some of the most important characteristics are the followings:

- Cylinder dimensions: from 55 to 200 mm diameter
- Single and double piston (double piston configuration as "worst case")

- Bearings
  - Polymer per Pneumatic
  - Brass per Hydraulic and for Pneumatic Low-High Temperature

For detailed information, see documents [D1], [D2] and Annexes.

2.2 Architecture

The Sub-Systems have a 1oo1 architecture.

2.3 Classification

The Subsystems can be classified as Type A device according to IEC 61508, having an hardware fault tolerance of 0.

Their application is a “Low Demand Mode” application.

2.4 Restrictions

The items of additional equipment are not part of the assessment.
In particular, shut-down valve is not part of the assessment.

3 SAFETY-RELEVANT CHARACTERISTICS

Objective of the safety-related action is to bring a unit and/or whole plant into a safe state.

The Safety Function is realised in the following way:

> *When an unsafe condition is detected, the controller (outside the subsystem) drives the actuator to close (open) the shut-down valve (blow-down valve)*

4 INSPECTION SPECIFICATIONS

4.1 Standards

No.	Reference	Title
[N1]	IEC 61508: 2010 Part 1÷7	Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems
[N2]	IEC 61511: 2003 Part 1÷3	Functional Safety – Safety Instrumented Systems for the process industry sector

4.2 Databases

No.	Reference	Title
[N3]	NPRD-95, RIAC 1995	Non electronic Parts Reliability Data
[N4]	FMD-97, RIAC 1997	Failure Modes/Mechanism Distributions
[N5]	NSWC-98/LE1	Handbook of Reliability Prediction Procedures for Mechanical Equipment
[N6]	Exida	Electrical and Mechanical Component Equipment Reliability Handbook
[N7]	OREDA	Offshore Reliability Data

5 INSPECTION DOCUMENTS

5.1 Documentation provided by the customer

No.	Reference	Title
[D1]	Rotork Sweden Technical Data	RC 200-DA/SR Technical Data
[D2]	Rotork Sweden Brochure	RC 200 Brochure
[D3]	Rotork Document KI-300537	SIL 3 Test

5.2 Documentation generated by TÜV Rheinland

No.	Reference	Title
[R1]	FMEA Rotork Sweden Attuatore.xls	FMEDA Calculation Rotork Sweden Actuators – Excel File

6 ABBREVIATIONS

β	Beta common cause factor
λ_{NE}	Failure rate of no effect failures
λ_{D}	Failure rate of dangerous failures
λ_{DU}	Failure rate of undetected dangerous failures
λ_{DD}	Failure rate of detected dangerous failures
λ_{S}	Failure rate of safe failures
λ_{SU}	Failure rate of undetected safe failures
λ_{SD}	Failure rate of detected safe failures
CL	Confidence Level
DC	Diagnostic Coverage factor
FSMS	Functional Safety Management System
FMEDA	Failure Mode Effect and Diagnostic Analysis
FIT	Failure In Time ($1x10^{-9}$ failures per hour)
HFT	Hardware Fault Tolerance
High demand mode	Mode, where the frequency of demands for operation made on a safety-related system is greater than one per year
Low demand mode	Mode, where the frequency of demands for operation made on a safety-related system is no greater than one per year
MTBF	Mean Time Between Failure
MRT	Mean Repair Time
PFD	Probability of Failure on Demand
PFD_{AVG}	Average Probability of Failure on Demand
PFH	Probability of Failure per Hour
RRF	Risk Reduction Factor
SAR	Safety Analysis Report
SRS	Safety Requirements Specifications
SFF	Safe Failure Fraction summarizes the fraction of failures, which lead to a safe state and the fraction of failures which will be detected by diagnostic measures and lead to a defined safety action
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
SIS	Safety Instrumented System – Implementation of one or more Safety Instrumented Functions. A SIS is composed of any combination of sensor(s), logic solver(s) and final element(s)
TI	Test Interval for Proof Test (Full-Stroke)
TI_{D}	Test Interval for Diagnostic Test (Partial-Stroke)
Type A component	“Non-Complex” component (using discrete elements)
Type B component	“Complex” component (using micro controllers or programmable logic)

7. PFD ESTIMATION

7.1 Procedure for PFD estimation

The PFD estimation (evaluation of random failures) is performed through an hardware demonstration of the device, based on a Failure Modes, Effects and Diagnostic Analysis (FMEDA).
The FMEDA was done based on the documentation provided (in particular drawings [D1], [D2]) by the Manufacturer and is documented in [R1].
A Failure Modes and Effects Analysis (FMEA) is a systematic way to identify and evaluate the effects of different components failure modes, to determine what could eliminate or reduce the chance of failure, and to document the system in consideration.
A FMEDA is an FMEA extension. It combines standard FMEA techniques with extension to identify online diagnostics techniques and the failure modes relevant to safety instrumented system design. It is a technique recommended to generate failure rates for each important category (safe detected, safe undetected, dangerous detected, dangerous undetected) in the safety models.

The PFD estimation was performed following the procedure described below:

1. FMEDA Analysis of the products.
2. Cyclic testing of the product.
3. Classification of failures (see the failure categories in subclause 7.3 of the present document).
4. Evaluation of λ values and, subsequently, of SFF and PFD.

7.2 Assumptions

The following assumptions have been made during the FMEDA evaluation and PFD estimation:

- Only a single component failure will fail the entire product.
- Propagation of failures is not relevant (unless an evident propagation process is present).
- Failure rates of components are taken from sources [N3]÷[N7].
- According to definitions 3.6.8, 3.6.13, 3.6.14 of IEC 61508-4, the safe, no part and no effect failures do not contribute to PFD_{AVG} calculations.
- Partial Stroke Test is considered as method of diagnosis.
- After a Full Stroke Test, with related Maintenance and Repair, the product will be “as new” (a “Proof Test Coverage” of 95% is used for the evaluation of SFF).
- The rate of “systematic failures” is controlled and minimised by the management of the “Safety Life Cycle” of the product.
- The installation, commissioning, operational and maintenance instruction are correctly applied by the final customer.
- The stress levels considered are average for an industrial environment (petrochemical industry – Ground Fixed).

7.3 Description of the failure categories

In order to judge the failure behaviour of the Subsystem, the following definitions for the failure of the subsystem were considered:

Safe Failure	Failure of an element and/or subsystem and/or system that plays a part in implementing the safety function that: a. results in the spurious operation of the safety function to put the EUC (or part thereof) into a safe state or maintain a safe state; or b. increases the probability of the spurious operation of the safety function to put the EUC (or part thereof) into a safe state or maintain a safe state Safe failures are divided into safe detected (SD) and safe undetected (SU) failures.
Dangerous Failure	Failure of an element and/or subsystem and/or system that plays a part in implementing the safety function that: a. prevents a safety function from operating when required (demand mode) or causes a safety function to fail (continuous mode) such that the EUC is put into a hazardous or potentially hazardous state; or b. decreases the probability that the safety function operates correctly when required Dangerous failures are divided into dangerous detected (DD) and dangerous undetected (DU) failures.
No Effect Failure	Failure of an element that plays a part in implementing the safety function but has no direct effect on the safety function
No Part Failure	Failure of a component that plays no part in implementing the safety function

NOTES:
1. According to definitions 3.6.13 and 3.6.14 of IEC 61508-4, the no part and no effect failures are not used for SFF calculations.
2. According to definitions 3.6.8, 3.6.13, 3.6.14 of IEC 61508-4, the safe, no part and no effect failures do not contribute to PFD_{AVG} calculations.

7.4 PFD estimation

FMEDA Analysis

The FMEDA Analysis was performed according to the following procedure:

a. complete definition of the product, including identification of internal and external interface functions, expected performance, system restraints and failure definition;
b. drawings of functional block diagrams;
c. association of each function to the components;
d. identification of all potential items and interface failure modes, including their effects;
e. evaluation of each potential failure mode in terms of local effect and end system effect and the worst potential associate consequence;
f. identification of the failure detection methods and compensating provisions for each failure mode (if possible);
g. association of a failure category to each failure mode.

The complete FMEDA is included in document [R1].

Cyclic testing of the product

The cyclic test has been carried using the procedure described in document [D3].
Photos of the tests are included in Annex E.

Classification of failures

Each single failure mode was classified, in document [R1], according to the description of the failure categories included in subclause 7.3 of the present document.

Evaluation of λ values, of SFF, PFD and PFD_{AVG}

Evaluation of λ values

The evaluation of λ values is based on the FMEDA.
The complete calculations for the evaluation of λ values are included in document [R1].

Evaluation of SFF

According to [N1], the SFF has to be calculated, in order to verify the suitability of a device for the usage in a SIS for a particular safety integrity level SIL.
The formula for SFF is the following:

$$SFF = \frac{\lambda_S + \lambda_{DD}}{\lambda_S + \lambda_D}$$

(where λ_{DD} means detected by the partial stroke test ($\lambda_{DD(PS)}$) and/or by the full stroke test ($\lambda_{DD(FS)}$))

The FMEDA gives the following result:

SFF= >99% (for Spring Return Actuators)
SFF= 95,00% (for Double Acting Actuators)

NOTE:

- SFF includes the effect of Full Stroke Test

Evaluation of PFD

According to document [N1], the following formula is used to estimate the PFD_{AVG} value:

$$PFD_{AVG} = \lambda_{DU} \cdot \left(\frac{TI}{2} + MRT \right) + \lambda_{DD} \cdot \left(\frac{TI_{PS}}{2} + MRT \right)$$

Using the estimated λ values, the PFD_{AVG} value for TI = 12 months, MRT=24 h, is:

PFD_{AVG} = 1,38E-04 (for Spring Return Actuators)
PFD_{AVG} = 1,77E-04 (for Double Acting Actuators)

8 OVERALL RESULT

The analysis gives the results summarized in the following tables.

Actuator Type	λ_D [1/h]	$\lambda_{DD(PS)}$ [1/h]	$\lambda_{DD(FS)}$ [1/h]	λ_S [1/h]	λ_{NE} [1/h]	SFF
Spring Return	3,14E-08	2,98E-08	2,98E-08	2,61E-07	3,22E-07	>99%
Double Acting	4,03E-08	3,82E-08	3,82E-08	0	5,09E-07	95,00%

Table 1: Failure rates and SFF values of Rotork Sweden Pneumatic and Hydraulic Single and Double Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO

		Test Interval Frequency (months)				
		6	12	24	36	48
Partial Stroke frequency (months)	1	1,51E-05	1,86E-05	2,56E-05	3,27E-05	3,97E-05
	2	2,60E-05	2,95E-05	3,65E-05	4,35E-05	5,05E-05
	3	3,69E-05	4,04E-05	4,74E-05	5,44E-05	6,14E-05
	6		7,30E-05	8,00E-05	8,70E-05	9,40E-05
	9				1,20E-04	
	12			1,45E-04	1,52E-04	1,59E-04

Table 2: PFD_{AVG} values Rotork Sweden Pneumatic and Hydraulic Single Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO according to IEC 61508 for different values of TI and TI_{PS}

Test Interval Frequency (months)				
6	12	24	36	48
6,95E-05	1,38E-04	2,76E-04	4,13E-04	5,51E-04

Table 3: PFD_{AVG} values of Rotork Sweden Pneumatic and Hydraulic Single Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO according to IEC 61508 for different values of TI (no Partial Stroke Test)

		Test Interval Frequency (months)				
		6	12	24	36	48
Partial Stroke frequency (months)	1	1,95E-05	2,41E-05	3,33E-05	4,25E-05	5,17E-05
	2	3,35E-05	3,81E-05	4,72E-05	5,64E-05	6,56E-05
	3	4,74E-05	5,20E-05	6,12E-05	7,04E-05	7,96E-05
	6		9,38E-05	1,03E-04	1,12E-04	1,21E-04
	9				1,54E-04	
	12			1,87E-04	1,96E-04	2,05E-04

Table 4: PFD_{AVG} values Rotork Sweden Pneumatic and Hydraulic Double Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO according to IEC 61508 for different values of TI and TI_{PS}

Test Interval Frequency (months)				
6	12	24	36	48
8,92E-05	1,77E-04	3,54E-04	5,31E-04	7,07E-04

Table 5: PFD_{AVG} values of Rotork Sweden Pneumatic and Hydraulic Double Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO according to IEC 61508 for different values of TI (no Partial Stroke Test)

<u>Considering the values above summarised, the Rotork Sweden Pneumatic and Hydraulic Single and Double Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO can be used up to SIL 3 as a “single device”.</u>

A user of the Rotork Sweden Pneumatic and Hydraulic Single and Double Acting Actuators Series RC, RCE, RCO, RCI, RCIO, RCT, RCOT, RCIT, RCIOT, RCC, RCCO can utilize this failure rates in a probabilistic model of a Safety Instrumented Function (SIF) to determine suitability in part for Safety Instrumented System (SIS) usage in a particular Safety Integrity Level (SIL).

These results must be considered in combination with PFD_{AVG} values of other devices of a Safety Instrumented Function (SIF) in order to determine suitability for a specific Safety Integrity Level (SIL).

9. STATUS OF THE DOCUMENT

9.1 Liability

TÜV Rheinland prepares reports based on methods advocated in International standards. Failure rates are obtained from third-party certificates, manufacturer's declarations or from a collection of industrial databases.

9.2 Releases

History:	R 3:	Explicitation of inclusion of Quick Option	Date: 2011-07-20
	R 2:	Revision of FMEDA Inclusion of result of cyclic tests	Date: 2011-03-15
	R 1:	Detailed evaluation of Safe and No Effect Failures	Date: 2010-09-14
	R 0:	Initial release	Date: 2010-07-31

Release status: Released to client
Authors: Carlo Tarantola

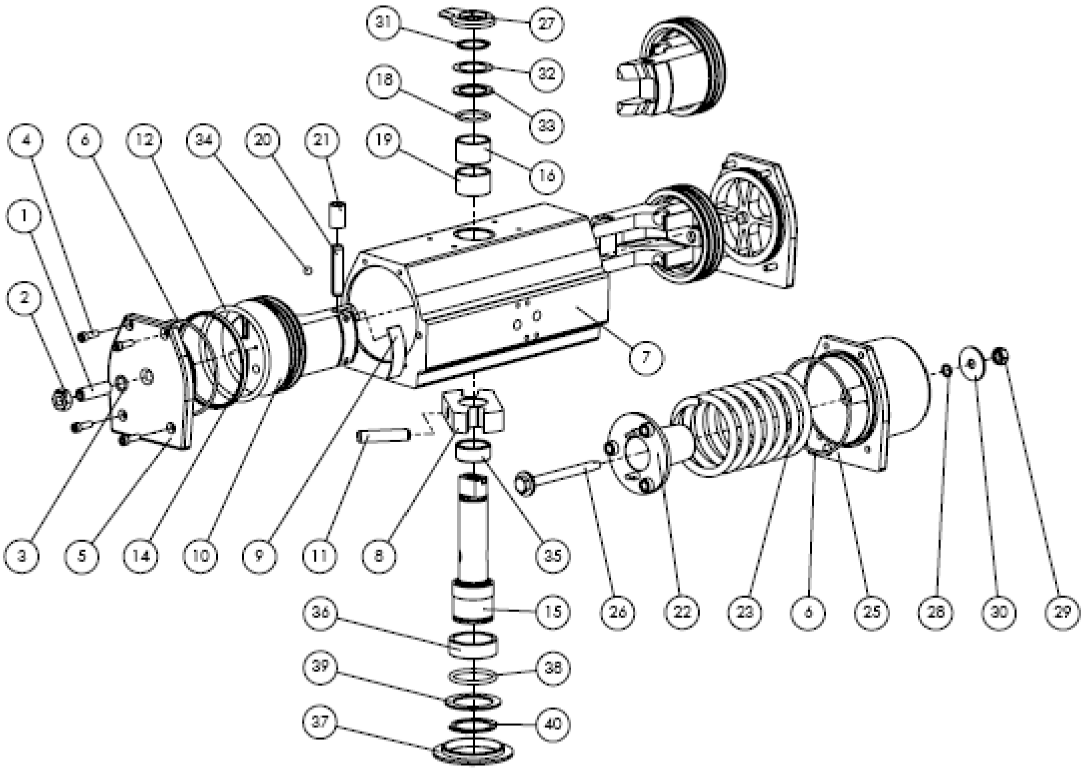
9.3 Future enhancements

On request of the customer.

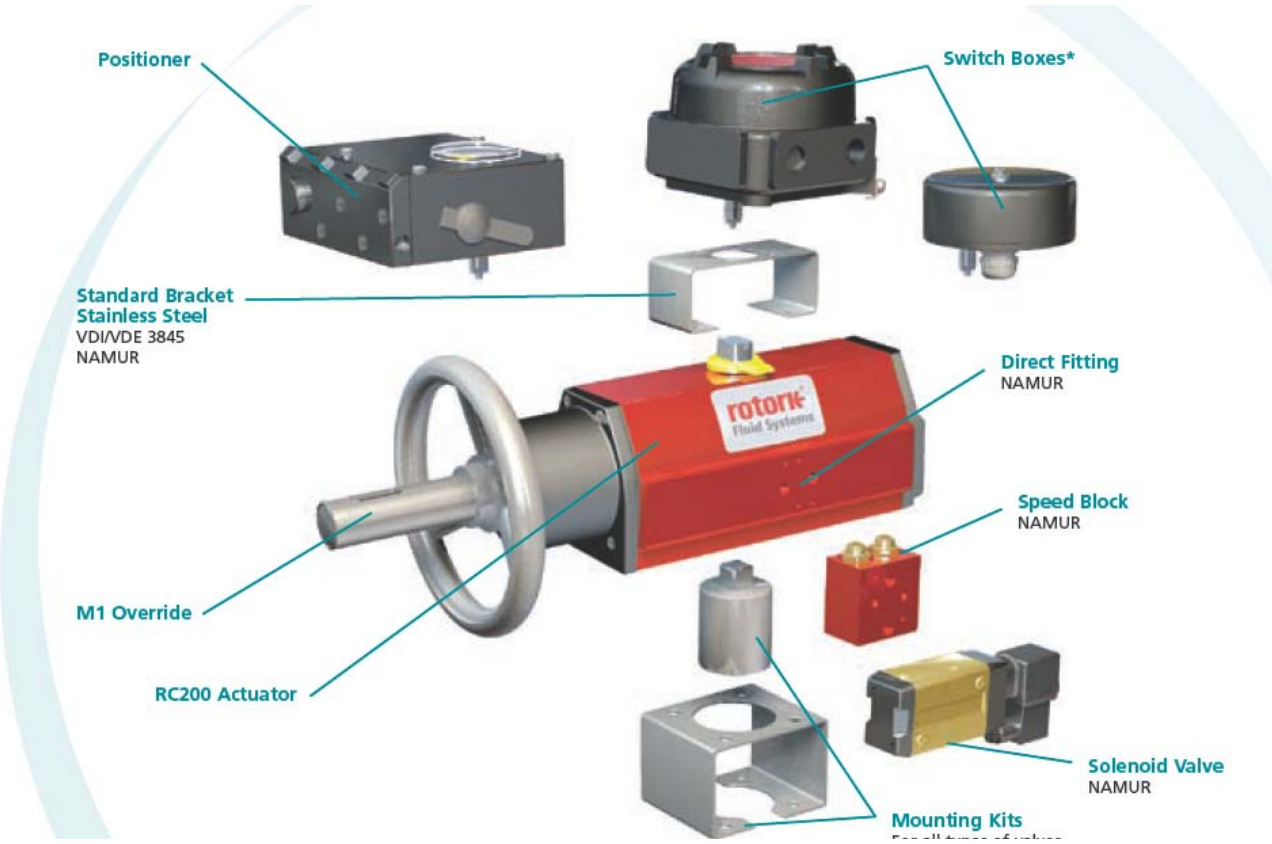
ANNEX A: PART LIST

Pos.	Article	Description	Quantity	Material	Drawing no.
-	113257	RC210-SR087 ACTUATOR F05F07-14	1	-	-
-	121169	LABEL	1	-	-
04	121111	SCREW MC6S 5 x 10 A2	8	Stainless steel	-
05	111130	EP2 10 (End plate with centre hole)	1	Aluminium	- see pos. 17
06	121019	O-RING 49,6x2,4	2	Nitrile	-
07	112175	CYLINDER	1	Aluminium	000559 C
08	112033	SY (Scotch Yoke)	1	Steel	000163 B
09	121053	SUE2 (Support element)	1	POM	116674 E
10	122342	PI2 1020 (Piston)	1	Aluminium	119443 D
11	121022	FRP 3,5x30 (Roll pin, double)	1	Spring steel	-
11	121023	FRP 6x30 (Roll pin, double)	1	Spring steel	-
12	121060	O-RING 47,22x3,53	1	Nitrile	-
14	122056	SUB2 1020 (Support band)	1	Polymer material	-
15	122297	DS2 1020-14 (Driving shaft)	1	Stainless steel	000512 E
16	121164	BE2 1020-U (Bearing, upper)	1	Polymer material	004582 A
17	121157	EP2 10 (End plate without centre hole)	1	Aluminium	119384 C, 000156 A
18	121016	O-RING 15,3x2,4	1	Nitrile	-
19	121164	BE2 1020-U (Bearing, upper)	1	Polymer material	004582 A
20	122058	PP2 1020 (Piston pin)	1	Steel	46504
21	121039	PR2 1020 (Piston roller) 6x10x12	1	Steel	-
22	121040	SG2 1020 (Spring guide)	1	Aluminium	000547 B
23	121116	S2 1020-087PSI (Spring)	1	Alloyed spring steel	105613 I
25	121155	SH2 1020 (Spring housing)	1	Aluminium	000582 D
26	122065	PS2 1020 L=75 (Pretensioning screw)	1	Stainless steel	127004 A
27	121095	INDICATOR RC210-220	1	Polymer material	46534
28	121017	O-RING 4,47x1,78	1	Nitrile	-
29	401158	LOCK NUT M6M M6 A4	1	Stainless steel	-
30	121128	MW2 1020-087PSI (Marking washer)	1	Aluminium	105043 E
31	121014	SGA 16 (Retaining ring, upper) 05-D20	1	Spring steel	-
32	121170	MIW2 1020 A2 (Middle washer)	1	Stainless steel	124324
33	121226	SUW2 1020-U (Support washer, upper)	1	Polymer material, chemically resistant	004140 B
34	121134	SEA2 1020 A2 (Sealing) 6,00mm	1	Stainless steel	-
35	121165	SUR2 1020-L (Support ring, lower)	1	Polymer material	123274 A
36	121163	BE2 1020-L (Bearing, lower)	1	Polymer material	004580 A
37	122050	GR2 1020 (Guide ring) F05	1	Polymer material	119524 B
38	141185	O-RING 24,2x3,0	1	Nitrile	-
39	121227	SUW2 1020-L (Support washer, lower)	1	Polymer material, chemically resistant	004141 A
40	121015	SGA 24 (Retaining ring, lower)	1	Spring steel	-

ANNEX B: GENERAL DRAWING



ANNEX C: PICTURES



ANNEX D: TECHNICAL DATA

RC200 design

Temperature range
Standard: -20ºC to +80ºC / -5ºF to +175 ºF
High temp: 0ºC to +150ºC /+30ºF to +300ºF
Low temp: -40ºC to +60ºC / -40 ºF to +140 ºF
Arctic: -47ºC to +60ºC / -52 ºF to +140 ºF

RC200 meet standards
Solenoid valve connection: NAMUR
Fitting accessories: VDI/VDE 3845, NAMUR
Fitting to valve: Hole pattern, centering ring ISO 5211, DIN 3337, NAMUR
Stardrive shaft: ISO 5211 with 90º and DIN 79 with 45º and NAMUR

RC200 are CE-marked
According to PED and ATEX.

Quick acting RC200 actuators
For quick operating times.

Pressure ranges
RC200-DA: 2-10 bar / 30-145 psi
RC200-SR: 2-10 bar / 30-145 psi

Extra corrosion protection
RCT hard anodised actuators
Epoxy finished
Offshore or other finish to meet customer specifications.
Stainless screws and drive shaft (standard for RC210-260)

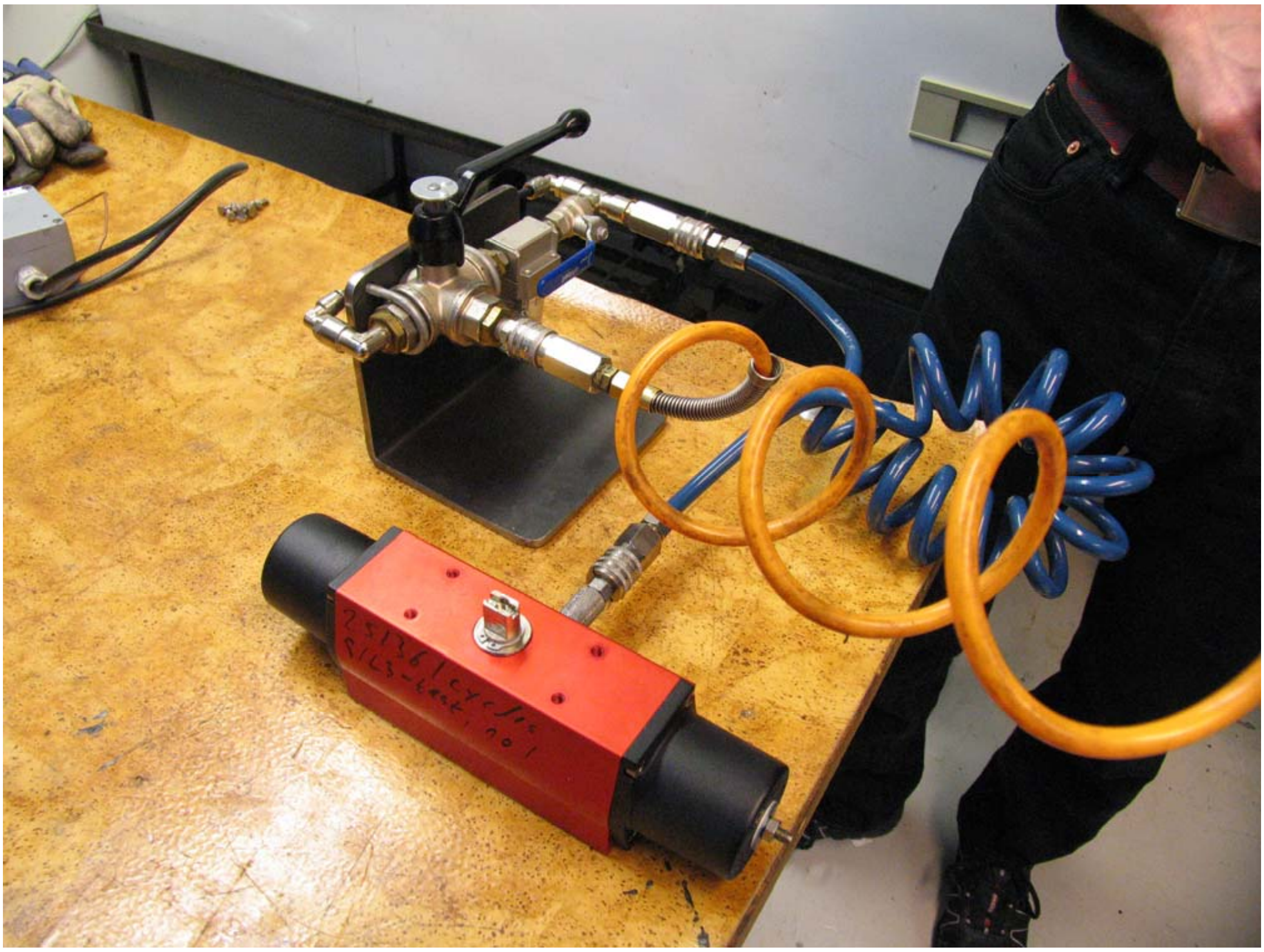
Operating medium
Air, inert gases (non-dangerous fluids, group 2 according to directive PED 97/23/EC)

RC200 actuators also available for Water or oil hydraulics: 2-10 bar / 30-145 psi

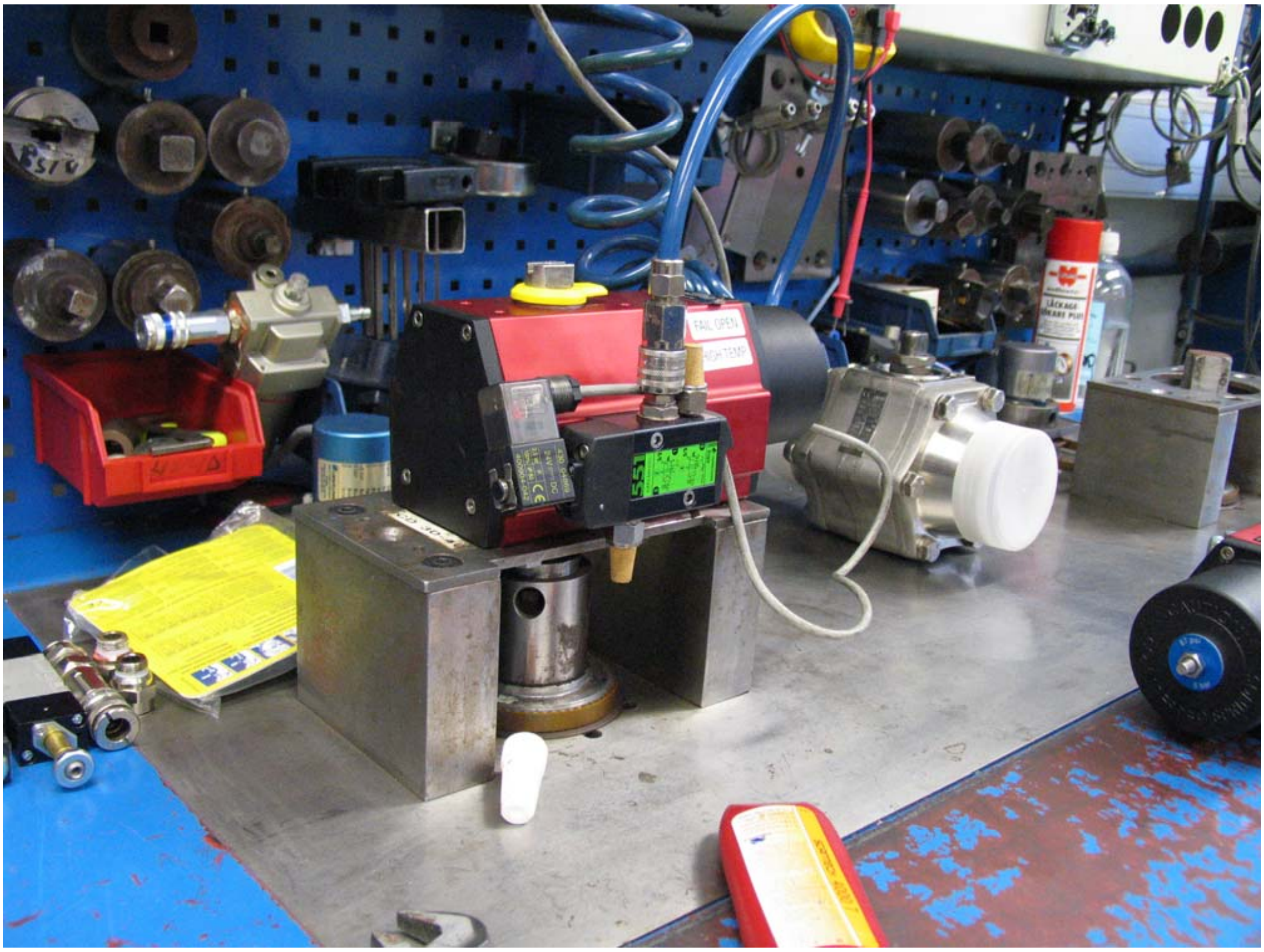
ANNEX E: PHOTOS OF THE TESTS

Test set-up in the at low temperature

Test set-up in the at high temperature



Final verification



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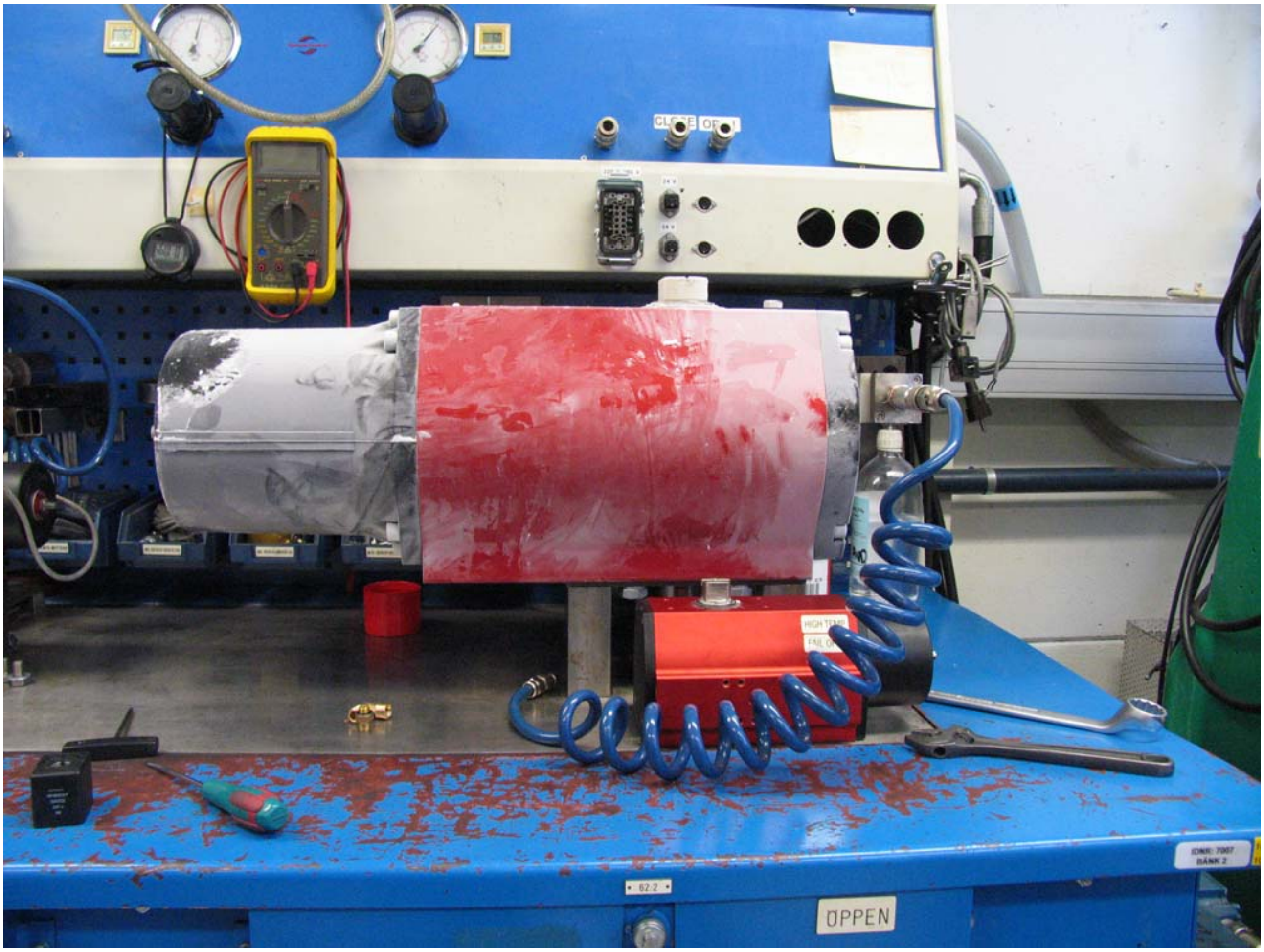

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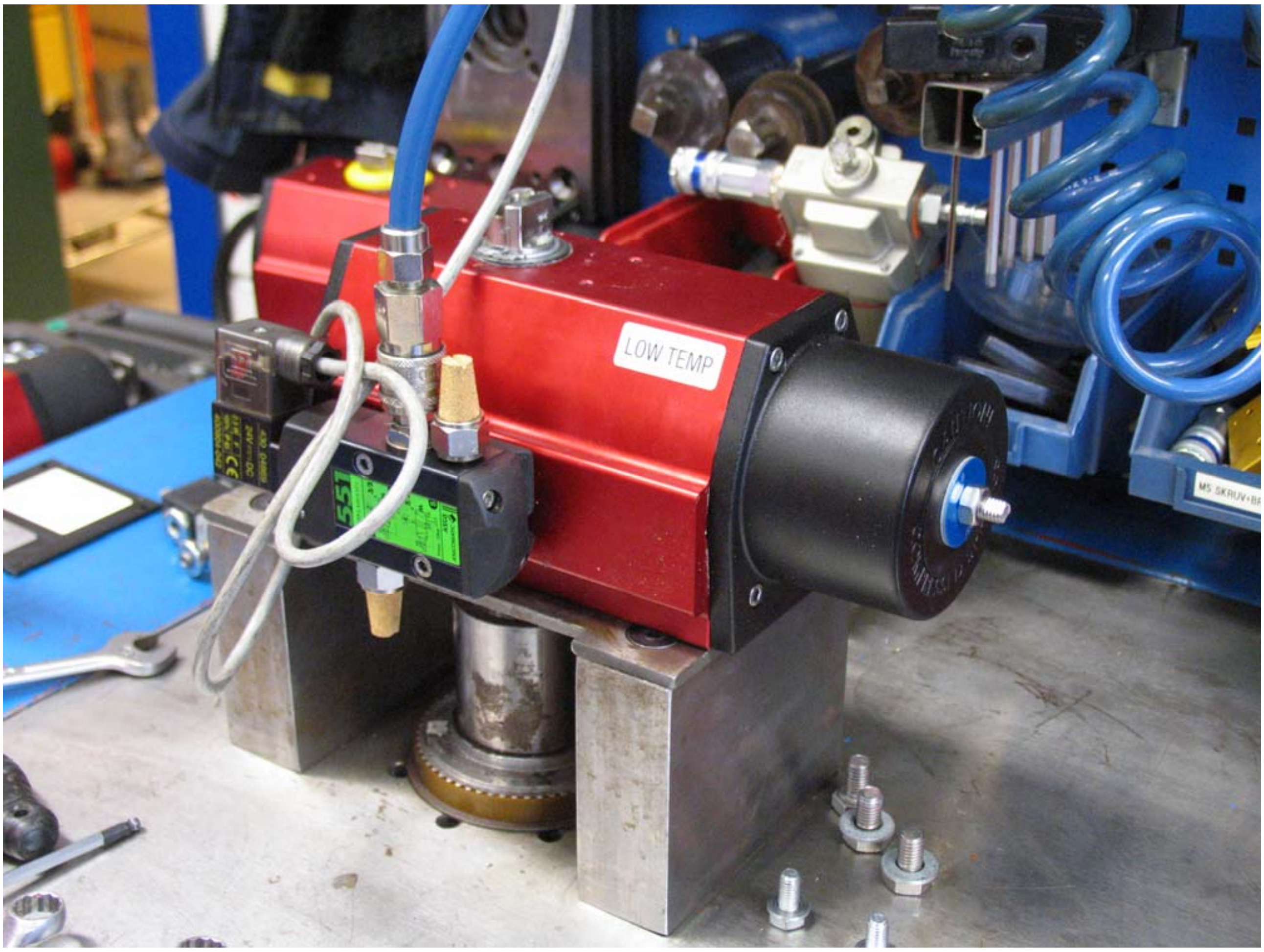

Final verification