Test Report No.:	*FS 28709155*
Version-No.:	*1.0*
Date:	*2009-06-15*
Subsystem:	*Linear Actuator*
Model:	*Series LH/S; LH/D; LP/S; LP/D*
Customer:	***Rotork Fluid Systems S.r.l.*** *Via del Casalino, 6* *I-55012 Tassignano (LU)*
Order No. / Date:	*Rotork Order dated 2009-03-25*
Test Specifications:	*IEC 61508: 2000 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. - TÜV Industrie Service*** *Div. Energy Systems and Automation* *Via Italia, 1* *24030 Medolago (BG)*
Author:	*Carlo Tarantola*
(Signature)	Carlo Tarantola

INDEX

PFD CALCULATION REPORT OF LINEAR ACTUATORS SERIES LH/S, LH/D, LP/S, LP/D

1 PURPOSE AND SCOPE

This report summarizes the results of a PFD evaluation of the Rotork Linear Actuators Series LH/S, LH/D, LP/S, LP/D.

A PFD evaluation was performed, according to IEC 61508-2 and IEC 61511-1, to evaluate the λ values and, consequently, the SFF and the PFD_{AVG} values of the Rotork Linear Actuators Series LH/S, LH/D, LP/S, LP/D.

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 Actuators Series:

- LH/S: Hydraulic linear Actuators, Single Acting (Spring Return)
- LH/D: Hydraulic linear Actuators, Double Acting
- LP/S: Pneumatic linear Actuators, Single Acting (Spring Return)
- LP/D: Pneumatic linear Actuators, Double Acting

Actuator	Max Operating Pressure	Max Thrust
LH/S	250 Bar	400.000 N
LH/D	250 Bar	5.500.000 N
LP/S	12 Bar	400.000 N
LP/D	12 Bar	1.800.000 N

Product Range Performance Data

Key design features of LH and LP range

- Carbon steel design single and double acting cylinders, electroless nickel plated
- Carbon steel piston with PTFE/Rubber seals
- Carbon steel, chromium plated piston rod
- Totally enclosed carbon steel spring cartridge

For detailed information, see document [D1] and Annex A.

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 (or Blow-Down Valve, for FAIL TO OPEN) is not part of the certification.

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) normally de-energizes a solenoid valve, which drives the actuator to:

a. *open a blow-down valve (FAIL TO OPEN)*
b. *close a shut-down valve (FAIL TO CLOSE)*

4 INSPECTION SPECIFICATIONS

No.	Reference	Title
[N1]	IEC 61508: 2000 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

5 INSPECTION DOCUMENTS

5.1 Documentation provided by the customer

No.	Reference	Title
[D1]	Rotork Publication F500E	LP and LH Range – Pneumatic and Hydraulic Linear Actuators
[D2]	Rotork Procedure PG4-04 Rev. 2 2005-10-11	Corrective and Preventive Actions
[D3]	Rotork Customer claims register	Customer claims register

5.2 Documentation generated by TÜV Rheinland

No.	Reference	Title
[R1]	Calcolo PFD Rotork Linear Actuators.xls	PFD Calculation Rotork Linear Actuators – Excel File

6 ABBREVIATIONS

β	Beta common cause factor
λ_{dc}	Failure rate of No Effect (Dont Care 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 and no greater than twice the proof test frequency
Low demand mode	Mode, where the frequency of demands for operation made on a safety-related system is no greater than one per year and no greater than twice the proof test frequency
MTBF	Mean Time Between Failure
MTTR	Mean Time To Restoration
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_{PS}	Test Interval for Diagnostic Test (Partial-Stroke)
Type A component	“Non-Complex” component (using discrete elements): for details, see 7.4.3.1.3 of IEC 61508-2
Type B component	“Complex” component (using micro controllers or programmable logic); for details, see 7.4.3.1.3 of IEC 61508-2

7. PFD ESTIMATION

7.1 Procedure for PFD estimation

The PFD estimation is performed through a "proven-in-use" demonstration of the device, according to subclauses 7.4.7.6÷7.4.7.12 of IEC 61508-2.

The PFD estimation was performed based on the database provided by the manufacturer [D3].

The PFD estimation was performed following the procedure described below:

1. Analysis of the list of field non conformities (failures database) of company Rotork.
   Rotork has a complete database of all the field non conformities of the latest 9 (nine) years.
   For the applicability of the "proven-in-use" method, the following two points were verified:
   a) Validity and reliability of the failures database, according to the criteria laid down in IEC 61508-2, subclauses 7.4.7.6÷7.4.7.12.
   b) Calculation of the Confidence Level, according to IEC 61508-2 subclause 7.4.7.9 and IEC 61508-7, Annex D.
2. Classification of failures (see the failure categories in subclause 10.3 of the present document).
3. Evaluation of λ values and, subsequently, of SFF, PFD and PFD_{AVG}.

7.2 Assumptions

The following assumptions have been made during the PFD estimation:

- Only a single component failure will fail the entire product.
- Propagation of failures is not relevant.
- Failures Rates are considered constant for the entire lifetime of the product.
- Partial Stroke Test is considered as a method of diagnosis. The DC of the Partial Stroke Test is determined classifying each type of failure according to the ability of the diagnosis method to detect it. For the DC of the Partial Stroke Test, taking in consideration that the system of Partial Stroke is not defined, a value of 75% is used.
- According to IEC 61511-1, the evaluation can be performed using the failure data for all the Actuators, those performing a safety function and those not performing a safety function[1].
- After a Full Stroke Test, with related maintenance and Repair, the Actuator will be "as new".
- 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).

[1] See IEC 61511-1, subclause 11.5.3.2, first note: *"In the case of field devices, (for example, sensors and final elements) fulfilling a given function, this is usually identical in safety and non-safety applications, which means that the device will be performing in a similar way in both type of applications. Therefore, consideration of the performance of such devices in non safety applications should also be deemed to satisfy this requirement".*

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 which has not the potential to put the Subsystem in a hazardous or fail-to-function state, i.e., the Subsystem does work on demand from the process. Safe failures are divided into safe detected (SD) and safe undetected (SU) failures.
Dangerous Failure	Failure which has the potential to put the Subsystem in a hazardous or fail-to-function state, i.e., the Subsystem doesn't work on demand from the process. Dangerous failures are divided into dangerous detected (DD) and dangerous undetected (DU) failures.
Safe Undetected Failure	Failure that is safe and that is not detected by diagnostics (Partial Stroke test).
Safe Detected Failure	Failure that is safe but is detected by diagnostics (Partial Stroke test).
Dangerous Undetected Failure	Failure that is dangerous and that is not detected by diagnostics (Partial Stroke test).
Dangerous Detected Failure	Failure that is dangerous but is detected by diagnostics (Partial Stroke test).

7.4 PFD estimation

Analysis of the list of field non conformities (failures database)

a) Management of failures

The management of failures (see documents [D2] and [D3]) proves that:

i. There is sufficient evidence that the great majority of failures are reported and analysed.
ii. The failures are correctly managed.
iii. The failures are correctly classified according to IEC 61508.

b) Validity and reliability of the failures database

The failures database of company Rotork proves that:

i. There is adequate documentary evidence which is based on the previous use of the Rotork Actuators.
ii. The documentary evidence demonstrates that the likelihood of any failure of the subsystem is low enough so that the required SIL of the SIF(s) which use the system is achieved.
iii. The previous conditions of use of the Actuators are similar to those that can be experienced in the future, in similar plants.
iv. All failures occurred are adequately detected and reported in the Rotork Failures Database.

c) Calculation of the Confidence Level (CL)

As required by IEC 61508-2, subclause 7.4.7.9, sufficient operational time is required to establish the claimed failure rate data to a lower confidence level of at least 70%[2].
The formula for the estimation of the number n of test cases (to reach a given CL) is the following (CL=1-α):

$$n \geq -\frac{\ln(\alpha)}{PFD_{AVG}}$$

For a SIL 3 application and CL=0,7, we obtain: *n≥12040*

In our situation, n is equal to the number of Actuators sold multiplied per the number of service years, multiplied per the number of demands per year (we suppose 1 demand per year).
From the data received from Rotork, we have:

n > 20.000 (for both LH and LP Series)

This value is higher than the value needed for the statistical calculation for SIL 3 applications.

From the above considerations, we can conclude that the Rotork Failures Database and the number of Actuators used for the statistical analysis are adequate for the application of the "proven-in-use" estimation of PFD, up to SIL 3 application.

[2] According to IEC 61508-2 subclause 7.4.7.9, the operational time of Actuators of less than one year is not considered for statistical analysis.

Classification of failures

Each single non conformity was classified, in document [D3], according to the description included in the same document, and according to the description of the failure categories included in subclause 7.3 of the present document.
In case of doubt, an extensive analysis was made, using the file referred to in document [D3].

For the classification of failures, the following types of Non Conformities were considered "Not Relevant", i.e. "Non Conformities which are non to be considered failures as intended in IEC 61508":

- Non Conformities which were noticed before the installation of the device, or during the initial testing of the device itself (e.g., non conformities due to mismatch of components, various kinds of leakages verified before the use of the device, incomplete materials)
- Non Conformities due to other devices (e.g., the electromagnetic valve)
- Non Conformities due to the final user (e.g., wrong use of the device)

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

Evaluation of λ values

From the classification of failures we obtain:

Actuator Series	λ_S [1/h]	λ_D [1/h]	$\lambda_{DD(PS)}$ [1/h]
LH/S	1,65E-07	1,32E-08	9,92E-09
LH/D	1,65E-07	1,32E-08	9,92E-09
LP/S	1,54E-07	1,31E-08	9,80E-09
LP/D	1,54E-07	1,31E-08	9,80E-09

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 SFF is the fraction of the overall failure rate of a device that results in either a safe fault or a diagnosed unsafe fault.

The formula for SFF is the following:

$$SFF = 1 - \frac{\lambda_{DU}}{\lambda_{TOTAL}}$$

Using the above estimated λ values, we obtain:

Actuator Series	SFF (no Partial Stroke Test)	SFF (with Partial Stroke Test)
LH/S	92,58%	94,43%
LH/D	92,58%	94,43%
LP/S	92,16%	94,12%
LP/D	92,16%	94,12%

These values are compatible up to a SIL 3 level.

Evaluation of PFD and PFD_{AVG}.

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

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

8 OVERALL RESULT

The analysis gives the results summarized in the following tables.

Actuator Series	λ_S [1/h]	λ_D [1/h]	$\lambda_{DD(PS)}$ [1/h]	SFF (no Partial Stroke Test)	SFF (with Partial Stroke Test)
LH/S	1,65E-07	1,32E-08	9,92E-09	92,58%	94,43%
LH/D	1,65E-07	1,32E-08	9,92E-09	92,58%	94,43%
LP/S	1,54E-07	1,31E-08	9,80E-09	92,16%	94,12%
LP/D	1,54E-07	1,31E-08	9,80E-09	92,16%	94,12%

		TI Frequency (months)				
		6	12	24	36	48
TI_{PS} frequency (months)	1	1,10E-05	1,82E-05	3,25E-05	4,68E-05	6,11E-05
	2	1,46E-05	2,18E-05	3,61E-05	5,04E-05	6,47E-05
	3	1,82E-05	2,54E-05	3,97E-05	5,40E-05	6,83E-05
	6		3,61E-05	5,04E-05	6,47E-05	7,90E-05
	9			6,11E-05	7,54E-05	8,97E-05
	12			7,19E-05	8,62E-05	1,00E-04

PFD_{AVG} values of Rotork Hydraulic Actuators Series LH/S, LH/D for different values of TI and TI_{PS} (with Partial Stroke Test)

TI Frequency (months)				
6	12	24	36	48
2,89E-05	5,75E-05	1,15E-04	1,72E-04	2,29E-04

PFD_{AVG} values of Rotork Hydraulic Actuators Series LH/S, LH/D for different values of TI (without Partial Stroke Test)

		TI Frequency (months)				
		6	12	24	36	48
TI_{PS} frequency (months)	1	1,12E-05	1,84E-05	3,29E-05	4,74E-05	6,19E-05
	2	1,48E-05	2,21E-05	3,65E-05	5,10E-05	6,55E-05
	3	1,84E-05	2,57E-05	4,02E-05	5,47E-05	6,91E-05
	6		3,65E-05	5,10E-05	6,55E-05	8,00E-05
	9			6,19E-05	7,64E-05	9,09E-05
	12			7,28E-05	8,73E-05	1,02E-04

PFD_{AVG} values of Rotork Pneumatic Actuators Series LP/S, LP/D for different values of TI and TI_{PS} (with Partial Stroke Test)

TI Frequency (months)				
6	12	24	36	48
2,93E-05	5,83E-05	1,16E-04	1,74E-04	2,32E-04

PFD_{AVG} values of Rotork Pneumatic Actuators Series LP/S, LP/D for different values of TI (without Partial Stroke Test)

Considering the values above summarised, the Rotork Linear Actuators Series LH/S, LH/D, LP/S, LP/D can be used up to SIL 3 as a "single device".

A user of the Rotork Linear Actuators Series LH/S, LH/D, LP/S, LP/D 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

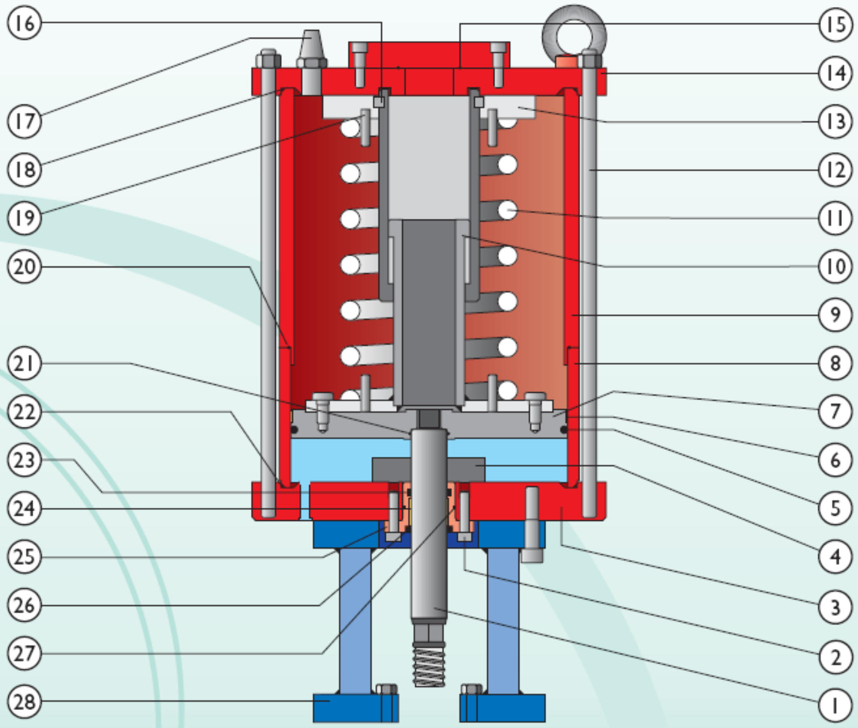
History:	R1.0:	Initial release	Date: 2009-06-15
Release status:	Released to client		
Authors:	Carlo Tarantola		

9.3 Future enhancements

On request of the customer.

ANNEX A: DRAWINGS

Pneumatic single acting, spring to close actuator illustrated

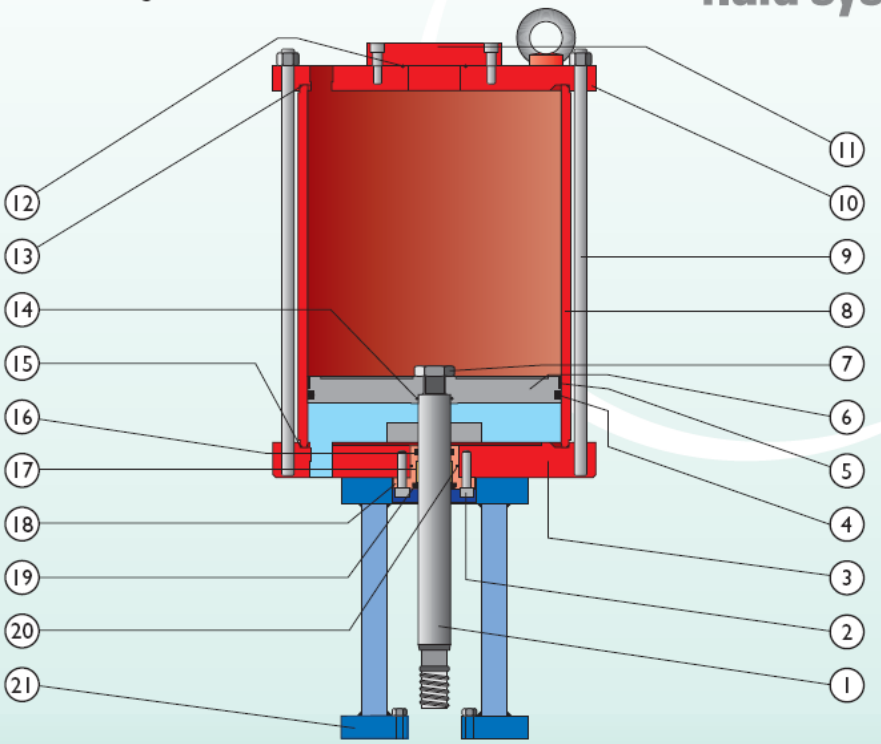


1	Piston Rod	Alloy Steel + Chrom. Plating	AISI SAE 9840 + Chrom. Plating
2	Screw	Carbon Steel	AISI SAE 1040
3	Head Flange	Carbon Steel	ASTM A283 Gr D
4	Spacer	Carbon Steel	ASTM A283 Gr D
5	O-Ring *	Buna-N	
6	Guide Sliding Ring *	PTFE	
7	Piston	Carbon Steel	ASTM A283 Gr D
8	Cylinder Tube	Carbon Steel + Nickel Plating	API 5LX Gr X52 (C$\leq$0.2%) + Nickel Plating
9	Spring Container Tube	Carbon Steel	API 5LX Gr X52 (C$\leq$0.2%)
10	Spring Retaining Tube Assembly	Carbon Steel	API 5LX Gr X52 (C$\leq$0.2%) + ASTM A 193 Gr D
11	Spring	Spring Steel	ASTM A29 Gr 9254
12	Tie Rod	Alloy Steel	AISI SAE 9840
13	Spring Guide Plate	Carbon Steel	ASTM A283 Gr D
14	Bottom Flange	Carbon Steel	ASTM A283 Gr D
15	O-Ring *	Buna-N	
16	Ring	Carbon Steel	
17	Silencer	Sintered Bronze	ASTM B427 Alloy 908
18	O-Ring *	Buna-N	
19	Elastic Pin	Spring Steel	ASTM A29 Gr 9254
20	O-Ring *	Buna-N	
21	O-Ring *	Buna-N	
22	O-Ring *	Buna-N	
23	Gasket *	Buna-N + PTFE + Graphite	
24	Bushing	Steel + Bronze + PTFE	
25	Bush	Carbon Steel	
26	Scraper Ring *	Buna-N + PTFE	
27	O-Ring *	Buna-N	
28	Adaptor	Carbon Steel	ASTM A283 Gr D

* = Recommended spare parts

Pneumatic double acting actuator illustrated

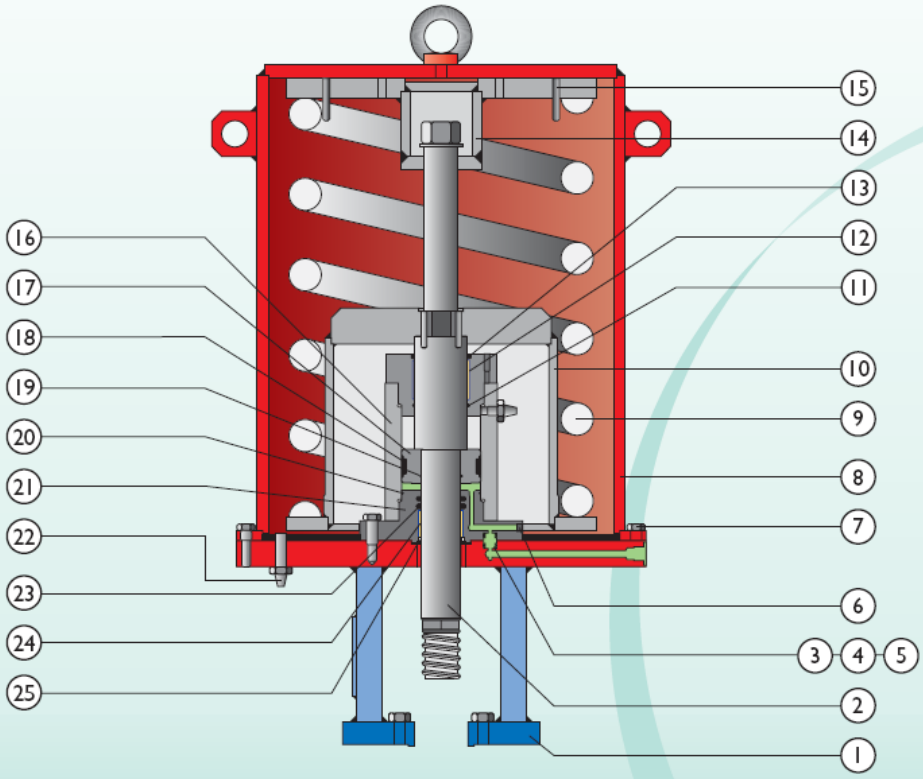
fluid system



1	Piston Rod	Alloy Steel + Chrom. Plating	AISI SAE 9840 + Chrom. Plating
2	Screw	Carbon Steel	AISI SAE 1040
3	Head Flange	Carbon steel	ASTM A283 Gr D
4	O-Ring *	Buna-N	
5	Guide Sliding Ring *	PTFE	ASTM A283 Gr D
6	Piston	Carbon Steel	ASTM A194 Gr 2
7	Nut	Carbon Steel	API 5LX Gr X52(C≤0.2%)+Nickel Plating
8	Cylinder Tube	Carbon Steel + Nickel Plating	AISI SAE 9840
9	Tie Rod	Alloy Steel	ASTM A283 Gr D
10	Bottom Flange	Carbon Steel	ASTM A194 Gr 2
11	Nut	Carbon Steel	ASTM A283 Gr D
12	O-Ring *	Buna-N	
13	O-Ring *	Buna-N	
14	O-Ring *	Buna-N	
15	O-Ring *	Buna-N	
16	O-Ring *	Buna-N	
17	Bushing	Steel + Bronze + PTFE	
18	Bush	Carbon Steel	
19	Gasket	Buna-N + PTFE	
20	O-Ring *	Buna-N	
21	Adaptor	Carbon Steel	ASTM A 283 Gr D

* = Recommended spare parts

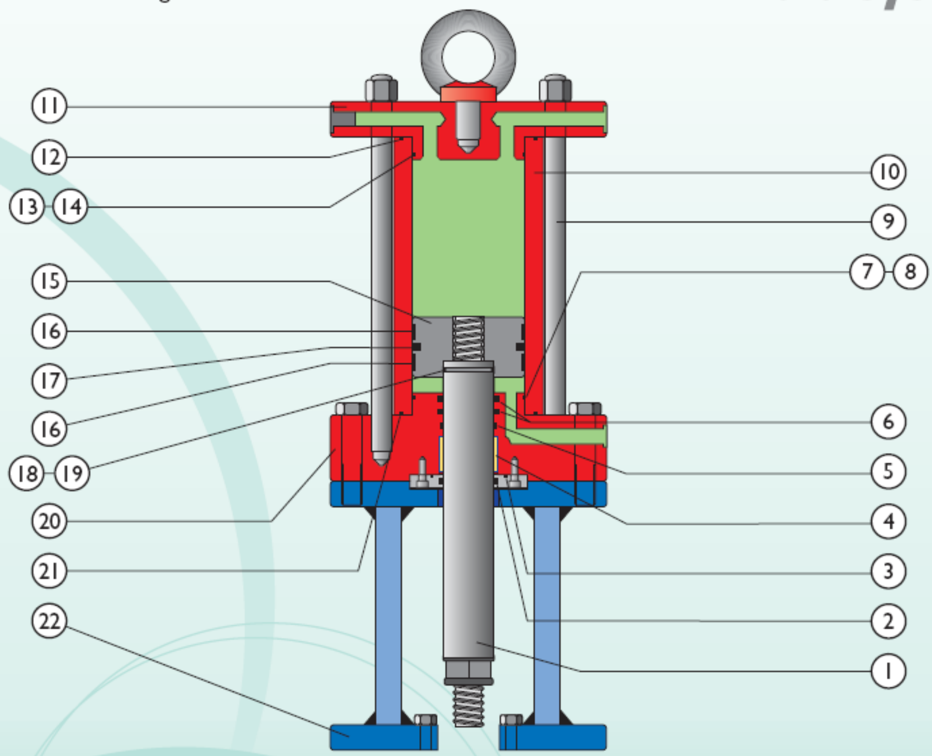
Hydraulic single acting, spring to close actuator illustrated



1	Adaptor	Carbon Steel	ASTM A283 Gr D
2	Piston Rod	Alloy Steel + Chrom. Plating	AISI / SAE 9840 + Chrom. Plating
3	Seal Bush	Carbon Steel	AISI / SAE 1040
4	O-Ring *	Buna-N	
5	Ring *	PTFE	
6	Plug	Carbon Steel	ASTM A105
7	Screw	Carbon Steel	AISI / SAE 1040
8	Cylinder Housing	Carbon Steel	API 5LX Gr X52 (C≤0.2%) + ASTM A283 Gr D
9	Spring	Spring Steel	ASTM A29 Gr 9254
10	Spring Driving Flange	Carbon Steel	API 5LX Gr X52 (C≤0.2%) + ASTM A283 Gr D
11	O-Ring *	Buna-N	
12	Bushing	Steel + Bronze + PTFE	
13	Scraper Ring *	Steel + Buna-N	
14	Spring Retaining Flange	Carbon Steel	API 5LX Gr X52 (C≤0.2%) + ASTM A283 Gr D
15	Elastic Pin	Spring Steel	ASTM A29 Gr 9254
16	Cylinder Tube	Carbon Steel + Nickel Plating	API 5LX Gr X52 (C≤0.2%) + Nickel Plating
17	Piston	Carbon Steel	AISI / SAE 1040
18	Piston Gasket *	Buna-N + PTFE	
19	O-Ring *	Buna-N	
20	O-Ring *	Buna-N	
21	Head Flange	Carbon Steel	ASTM A283 Gr D
22	Silencer	Sintered Bronze	ASTM B427 ALLOY 908
23	Gasket *	Buna-N + PTFE + Bronze	
24	Bushing	Steel + Bronze + PTFE	
25	Scraper Ring *	PTFE + Buna-N	

* = Recommended spare parts

Hydraulic double acting actuator illustrated



ITEM	DESCRIPTION	MATERIAL	U.S. STANDARD EQUIVALENT
1	Piston Rod	Alloy Steel + Chrom. Plating	AISI / SAE 9840 + Chrom. Plating
2	Scraper Ring *	Buna-N + PTFE	
3	O-Ring *	Buna-N	
4	Bushing	Steel + Bronze + PTFE	
5	Sliding Ring *	PTFE	
6	Gasket *	Buna-N + PTFE + Bronze	
7	O-Ring *	Buna-N	
8	Back-up Ring *	PTFE	
9	Tie Rod	Alloy Steel	AISI / SAE 9840
10	Cylinder Tube	Carbon Steel + Nickel Plating	API 5LX Gr X52 (C≤0.2%)+Nickel Plating
11	Bottom Flange	Carbon Steel	ASTM A283 Gr D
12	O-Ring *	Buna-N	
13	O-Ring *	Buna-N	
14	Back-up Ring *	PTFE	
15	Piston	Carbon Steel	AISI / SAE 1040
16	Sliding Ring *	PTFE	
17	Gasket *	Buna-N + PTFE + Bronze	
18	O-Ring *	Buna-N	
19	Back-up Ring *	PTFE	
20	Head Flange	Carbon Steel	ASTM A283 Gr D
21	O-Ring *	Buna-N	
22	Adaptor	Carbon Steel	ASTM A283 Gr D

* = Recommended spare parts