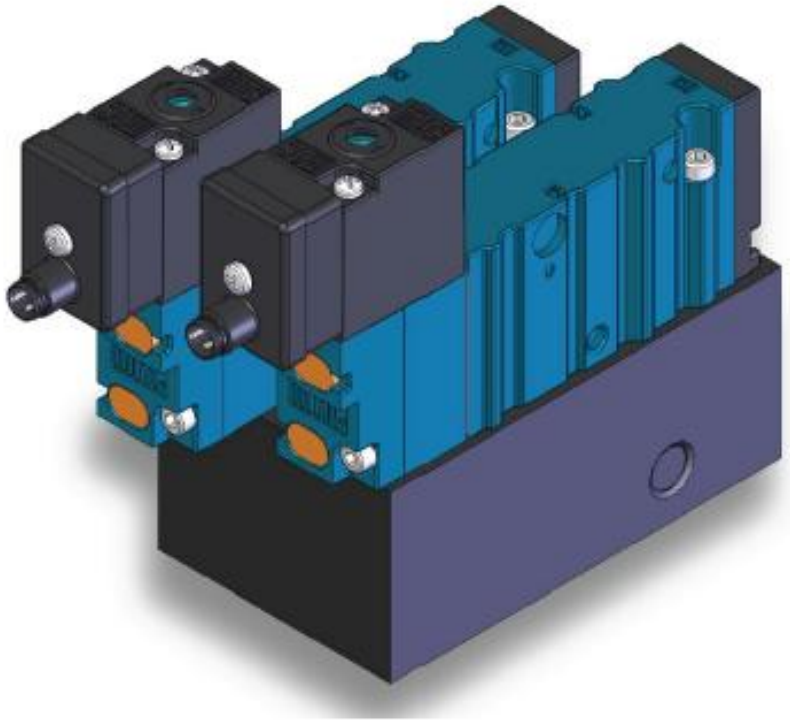
REDUNDANT SUPPLY AND EXHAUST ASSEMBLIES

MAC VALVES TYPE 52, 54 AND 67



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	Belgium	U.S.A.	Taiwan 320-63
PRODUCT/TEST ITEM	**3/2 solenoid valve redundant supply & exhaust assemblies**		
Type designation	52 Series	54 Series	67 Series
Port Size	1/8”-1/4”	3/8”-1/2”-3/4”	¾”-1”
Max flow	1200 Nl/min	5100 Nl/min	20000 Nl/min
Pressure range internal pilot	2.1 – 8.0 Bar	2.1 – 8.0 Bar	2.1 – 8.0 Bar
Pressure range external pilot	Vacuum to 8.0 Bar	Vacuum to 8.0 Bar	Vacuum to 8.0 Bar
Temperature range	0°C to + 50°C		

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OBJECTIVE

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The goal of this safety manual is to make all users of MAC solutions especially developed for safety system familiar with the main standards dealing with safety instrumented solution.
It has to assist people involved in safety related application in the definition and the selection of the right safety systems and components.

1. INTRODUCTION

The standards MAC Valves solutions are dealing with are :

- IEC 61508
- IEC 61511
- ISO 13849

All of those standards deal with the safety of machines.
They are all related to European directives applying to the safety of industrial machinery :

- Machine directive (2006/42/EC) for machine manufacturers
- The use of work equipment by workers and work directive for users

The directives fix the general rules for the safety on machines.
The standards fix the specifications for the different parts of the machines

2. MACHINE DIRECTIVE 2006/42/EC

This directive is related to the safety of machinery.

For the purpose of the directive, a machinery is an assembly fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application.

It specifies that the machine has to be designed, developed and constructed in order to ensure the highest level of safety.

The machine directive covers the supply of new machinery and other equipment including safety components. Provisions and requirements of the directive have to be met for all machines supplied within the EU.

The Annex 1 of the directive gives a list of Essential Health and Safety Requirements (EHSR) to which machinery must comply where relevant. The purpose of this list is to ensure that the machinery is safe

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and is designed and constructed so that it can be used, adjusted and maintained throughout all phases of its life without putting persons at risk.

The directive involves an explicit requirement for a risk assessment for the determination of which EHSRs are applicable.

The EHSR provides a hierarchy of measures for eliminating the risk :

- inherently safe design
- additional protective devices
- personal protective equipment and/or training

The requirements listed in the directive are :

- suitable materials used for construction and operation
- adequate lighting and handling facilities
- safe and reliable controls and control systems
- machines not capable of starting up unexpectedly a with one or more emergency stop devices
- consideration given to complex installations where processes upstream or downstream affect safety of machine
- failure of power supply of control circuit must not lead to a dangerous situation
- machines stable and capable of withstanding foreseeable stresses
- no exposed edges or surfaces likely to cause injury
- guards or protection devices to be used to protect risks such as moving parts
- electrical and other energy supply hazards to be prevented
- minimum risk of injury from temperature, explosion, noise, vibration, dust, gases, radiation
- proper instruction for maintenance and servicing
- sufficient indication and warning devices to be provided

Harmonized European Standards (EN) listed in the Official Journal of the European Union (OJ) under the Machinery Directive and whose date of cessation of presumption of conformity has not expired, confer a presumption of conformity with certain of the EHSRs. The task of demonstrating conformity with the EHSRs is greatly simplified for equipment complying with such current harmonized European standards.

IEC/EN 61508-61511 and ISO13849 are the standards that provide information about how to design and size safety related parts of control systems. They classify hierarchical levels of performance for safety related parts of control systems and provide risk assessment methods to determine the integrity requirements for a protective system.

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It is the responsibility of the machine manufacturer to ensure that all EHSRs are satisfied and to conduct a documented risk assessment to ensure that all potential machine hazards are addressed.

RISK ASSESSMENT

This section applies both to machine manufacturers and machine users.
The manufacturer needs to ensure that his machine is capable of being used safely.
The risk assessment should be started at the machine design phase and it should take account of all the foreseeable tasks than will need to be performed on the machine.

The risk assessment is made of the following steps :

- define the limits of the machine : to foresee all operation and use of the machine
- identify each hazard situation
- estimate the level of risk due to the hazard
- evaluate the risk : if risk too high, the risk must be reduced by addressing the hazard by a process, by redesign or by additional measures
- determine whether the performance and functional characteristics of safety measures are suitable for the machine and its type of use

For estimating the level of the risk, many factors have to be taken into account :

- the severity of potential injury
- the frequency of exposure
- the probability of injury

For reducing the risk, three basic methods have to be considered and used in the following order :

- eliminate and reduce risks as far as possible (inherently safe machine design and construction)
- to install the necessary protective systems and measures in relation to risks that can not be eliminated by design
- to inform users of the residual risk due to any shortcomings of the protection measures adopted, indicate whether any particular training is required and specify any need to provide personal protection equipment

The choice of protective device or system should be heavily influenced by the operating characteristics of the machine. The safety of the machine will depend on the proper application and correct operation of the protective system even under fault conditions.

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The safety system must be designed with a level of integrity that is commensurate with the risks of the machine. Higher risks require higher integrity levels to ensure the performance of the safety function. Machine safety systems can be classified into levels of performances of their ability to ensure the performance of their safety function or, in other words, their functional safety integrity level.

3. STANDARDS

Functional safety is the part of the overall safety that depends on the correct functioning of the process or equipment in response to its inputs.

Most significant standards for functional safety of machine safety systems are :
1. IEC 61508 : Parts 1-2 and 4-7:2010
2. IEC 61511 : Parts 1- 3: 2004
3. ISO 13849 : Part 1: 2006

All standards cover safety related electrical control systems.
They are intended to provide users with an option to choose the one most suitable for their situation.
The outputs of both standards are comparable levels of safety performance or integrity.

IEC 61508

IEC 61508 covers the functional safety of electrical/electronic/programmable electronic-safety related systems. Its main objective is to reduce the risk to a tolerable level in safety related application. It is used mainly by safety equipment suppliers to show that their equipment is suitable for use in safety integrity level rated systems. As supplier of air valves to be used on safety related equipment, MAC Valves specific solutions have to conform to this standard.

IEC 61511

IEC61511 covers the use of electrical/electronic/programmable electronic-safety related systems in the process industry. Like IEC 61508 if focuses on a set of safety lifecycle processes to manage process risk. Unlike IEC 61508, this standard is targeted for process industry users of safety instrumented systems. As supplier of air valves susceptible to be used on industry processes, MAC Valves specific solutions have to conform to this standard.

EN ISO 13849

EN ISO 13849 covers the safety of machines and more specifically the safety parts of control systems. It provides requirements for the design and the integration of safety-related parts of control systems. The standard applies to a safety-related system but can also be applied to the component parts of the

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system. This standard has a wide applicability, as it applies to all technologies including electrical, hydraulic, pneumatic and mechanical. MAC Valves specific solutions have to conform to this standard.

4. IEC 61508/61511

4.1. DEFINITIONS

For a better understanding of what the standard says, it is important to introduce already the terms and definitions used in both standards

Failure modes

The ways that a device fails : they are generally grouped into one of four modes

- safe detected
- dangerous detected
- safe undetected
- dangerous undetected

Failure rate

- The number of failures per unit of time for a piece of an equipment : usually assumed to be a constant value

Hardware Fault tolerance

- Ability of a functional unit to continue to perform a required function in the presence of random faults or errors.
- Single channel devices have a Hardware Fault tolerance of 0.
- Double channel devices have a hardware fault tolerance of 1.

FMEA

Failure Mode and Effect Analysis : detailed analysis of the different failure modes and solution to prevent the failures

Functional safety

- Freedom from unacceptable risk achieved through the safety lifecycle
- part of the overall safety that depends on the correct functioning of the process or equipment in response to its inputs

Hazard

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Event which has the potential to cause harm such as personal injury, damage to the environment or the business

HAZOP

Hazard and Operability Study : method highly structured that divides the process into different operationally based nodes and investigates the behavior of the different parts of each node when deviation of the standard conditions of use

IPL

- Independent Protection Layers : using safety instrumend system consisting of independent protection layers allow to reduce risk generated by the process.
- Used in LOPA analysis

Lambda (λ)

- Failure rate of a system : λ = F/T where F represents the number of failures and T the total number of device hours (running time, miles, cycles, etc) during an investigation period for both failed and non-failed items.
- Failures can be classified in dangerous, safe and non safety related.

Likelihood

- The frequency of a harmful event expressed in events per year or per millions of hours
- One of the two components used to quantify a risk
- The other component is the impact of the hazard on people, environment, costs

LOPA

Layer of Protection Analysis : method of analyzing the likelihood of a harmfull event based on an initiating event frequency and on the probability of failure of a series of independent layers of protection

Mode (continuous)

- When demands to activate a safety function (SIF) are frequent compared to the test interval of the SIF.
- The continuous mode is where the frequency of an unwanted accident is essentially determined by the frequency of a dangerous SIF failure

Mode (high demand)

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Similar to continuous mode but here automatic diagnostics are run many times faster than the demand rate on the safety function

Mode (low demand)

When demands to activate the safety instrumented function (SIF) are infrequent compared to the test interval of the SIF.

MTBF/MTTF

- Mean Time Between Failure / Mean Time To Failure
- MTBF refers to items that are repaired when they fail.
- MTTF refers to items that are thrown away and replaced (f.g. air valves)
- Both expresses

PFD/PFH

- Probability of dangerous failures : it is the failure rate (λ) expressed for dangerous failures multiplied by the time over which the probability has to be checked
- PFD : Probability of failures on demand mode (per year)
- PFH : probability of failures on continuous mode (per hour)

Redundancy

- Use of multiple elements or systems to perform the same function :
- redundancy is used to improve reliability and availability

Reliability

- the probability that a device will perform its objective adequately, for the period specified, under the conditions of use specified
- the probability that a component, piece of equipment or system will perform its intended function for a specified period of time, usually operating hours, without requiring corrective maintenance.
- The reliability (R) is calculated based on the failure rate (λ) and the time at which it has to be considered

Risk

- Likelihood that a hazard will cause a measurable adverse effect.
- For risk related to processes, it is usual to use the following values in order to estimate if the risk is acceptable or not
  1. risk of death of one in a million, per year, for both employees and members of the public should

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be used as a the broadly acceptable risk boundary

2. individual risk of death of 1 in 1000 per year should represent the boundary condition between what is just tolerable for workers and unacceptable for both employees and members of the public

SIF

- Safety Instrumented Function : a set of equipment intended to reduce the risk due to a specific hazard.
- automatically takes an industrial process to a safe state when conditions are violated
- permits a process to move forward in a safe manner when specified conditions allow
- taking action to mitigate the consequences of an industrial hazard

SIL

Safety Integrity Level : a quantitative target

- measures the level of performance needed for a safety function in order to achieve a tolerable risk for a process hazard
- expresses the level of safety required for an existing process
- measures the level of performance of a safety instrumented function and a safety instrumented system.
- Using safety instrumented functions and safety instrumented systems with appropriate SIL levels allows to bring the risk of an existing process below the tolerable level

SIS

Safety Instrumented System : implementation of one or more Safety Instrumented Functions

4.2. SCOPE OF IEC 61508-61511

IEC 61508 covers the functional safety of electrical/electronic/programmable electronic-safety related systems.
IEC61511 covers the use of electrical/electronic/programmable electronic-safety related systems in the process industry.

They are both related to safety related systems.

Air valves used on safety related systems are falling within the scope of the standards.
Safety related systems are used on several kinds of processes and industries in order to reach a certain level of safety. The level of the safety to be reached and the measures to be taken in order to reach it depend on the severity and the frequency of the risks generated by the process.

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The standards are intended for people who develop, design, install, repair, maintain, manage electrical, electronic and electronic programmable safety systems or components for safety systems.

The standards cover the all lifecycle of a safety related system starting with the analysis of the risk and ending with the decommissioning of the system.

They allow to :

- determine the level of the risk of a process based on the severity and the frequency of the risk
- determine the level of risk that is tolerated by the process
- determine the need for a safety system
- determine the level of the safety level to be achieved by the safety system
- determine the architecture of the safety system
- determine the components to be used in order to achieve the level of safety in the safety system
- calculate the level of safety of the safety system
- design the safety system
- install the safety system
- maintain, manage and repair the safety system
- decommission the safety system

In order to do this, the standards divide the safety management in different lifecycle phases :

- phase 1 : Hazard and risk assessments
- phase 2 : allocation of safety functions to protection layers
- phase 3 : safety requirements specification (SRS) for the Safety Instrumented Systems (SIS)
- phase 4 : design and engineering for the Safety Instrumented Systems
- phase 5 : installation, commissioning and validation of the SIS
- phase 6 : operation and maintenance of the SIS
- phase 7 : modification of the SIS
- phase 8 : decommissioning of the SIS
- phase 9 : verification of the SIS
- phase 10 : management functional safety – functional safety assessment and auditing
- phase 11 : safety lifecycle structure and planning

Each phase of the lifecycle describes an activity and each activity has information requirements as inputs and produces documents as outputs. Each phase consists of an activity for which documented procedures are required.

PHASE 1 : HAZARD AND RISK ASSESSMENT

Goal :

- determine the hazards

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- determine the risk generated by the process
- determine the level of risk tolerable by the process
- compare the risk generated by the process to the risk that is tolerable
- to pose the requirements for the risk reduction
- to determine the safety systems required to achieve the necessary risk reduction

Hazard :

- most common technique for identifying the hazards : HAZOP (Hazard and Operability Study)
- HAZOP identifies potential hazards and operability problems caused by deviation from the design intent

Risk

- likelihood that a hazard will cause a measurable adverse effect
- has to be quantified in 2 dimensions :
  1. the impact of the hazard on people, environment and costs
  2. the probability of occurrence of the hazard (see figure 1)

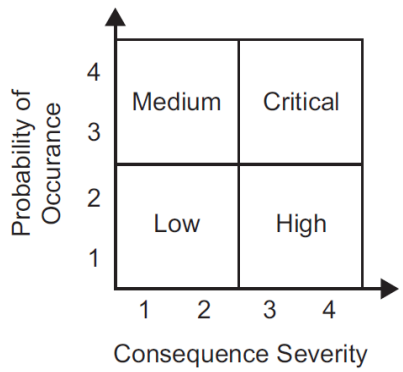

Figure 1 : risk matrix

- for risk related to processes, it is usual to use the following values in order to estimate if the risk is acceptable or not (Figure 2)
  1. risk of death of one in a million, per year, for both employees and members of the public corresponds to a very low level of risk and should be used as the broadly acceptable risk boundary
  2. individual risk or death of 1 in 1000 per annum should represent the boundary condition between what is just tolerable for workers and what is unacceptable for any groups

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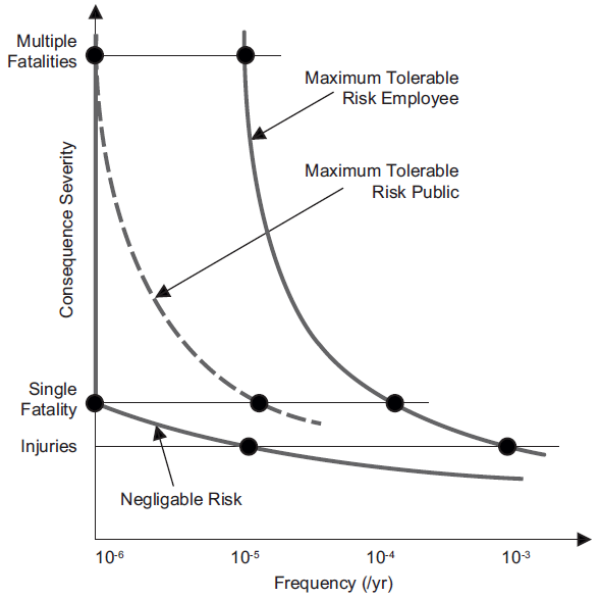

Figure 2 : acceptable risk

Risk reduction

- Depending upon risk associated to the hazard, a maximum tolerable frequency will be allocated to the hazard
- If the process is not able to keep the risk below this frequency, additional safety function will be engineered to reduce the risk below its acceptable level
- SIL measures the ability of a safety instrumented system and safety instrumented function to reduce a risk to a tolerable level
- SIL allows also to estimate the level for the tolerable risk for a process

SIL

- Safety Integrity Level
- Is a numerical reliability measure categorized by value into bands of safety levels : there are 4 levels (SIL4 provides the highest reliability, SIL1 the lowest)
- Quantifies the ability of a safety instrumented system and of a safety instrumented function to reduce the risk
- Measures the reliability of a safety instrumented system and a safety instrumented function
- Is linked to the probability of dangerous failures
- The probability of dangerous failures may be expressed for 2 modes of operation :
  1. probability of dangerous failures on demand mode
  2. probability of dangerous failures on continuous mode

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- Probability of dangerous failures on demand mode : frequency of operation of the safety system or function lower than once a year and infrequent compared to the test interval of the SIS or SIF. The probability is considered over a period of time of one year
- Probability of dangerous failures on continuous mode : frequency of operation of the safety system higher than once a year and frequent compared to the test interval of the SIL or SIL. The probability is considered over a period of time of one hour
- MAC air valves that are suspected to be operated many times a year belong to the continuous mode (1 operation per hour)

Demand Mode of Operation (Average probability of failure to perform its design function on demand)	**Safety Integrity Level**
$\geq 10^{-5}$ to $<10^{-4}$	4
$\geq 10^{-4}$ to $<10^{-3}$	3
$\geq 10^{-3}$ to $<10^{-2}$	2
$\geq 10^{-2}$ to $<10^{-1}$	1

Figure 3 : link between SIL and PFD in low demand mode

Continuous Mode of Operation (Probability of dangerous failure per hour, PFH)	**Safety Integrity Level**
$\geq 10^{-9}$ to $<10^{-8}$	4
$\geq 10^{-8}$ to $<10^{-7}$	3
$\geq 10^{-7}$ to $<10^{-6}$	2
$\geq 10^{-6}$ to $<10^{-5}$	1

Figure 4 : link between SIL and PFH in continuous mode

Procedure to determine the SIL of safety instrumented system used on an existing process:

- Estimate the probability of dangerous failures generated by the process
- if the process consists of different functions, each function of the process has to be analyzed conferring a probability of dangerous failure for each of them. Having these values and a good understanding of all the function operate together will allow to estimate the probability of failure for the complete process

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- an HAZOP analysis can be lead in order to estimate the probability of dangerous failures generated by the process
- identify the maximum level of risk required by the process
- many different analysis to identify the level of the risk required by the process : risk matrix, graph risk, LOPA
- compare the risk generated by the process to the risk tolerated and express the level of safety of the safety instrumented system
- determine the safety instrumented functions that will be part of the safety instrumented system
- express the level of safety of each safety related function (f.g. pressure supply, exhaust to atmosphere)
- check if the SIL offered by the safety system is matching the SIL level requested by the risk management

SIL evaluation for safety related function

- SIL values for safety related function may be determined by calculation
- Calculation is based on lifetime characteristics of the components used in SIF
- Lifetime characteristics obtained by experience, tests, tables of values

SIL evaluation for safety related systems

- A safety related system consists of more safety related functions
- The SIL calculation for the whole system is based on the SIL of each function and the way all functions are interfering and connected together

Risk graph analysis (Figure 5)

- This analysis allows a much deeper analysis of the risk based on the nature of the risk, the exposure to the risk, the possibility to avoid the risk and the probability that the hazard will occur (W1 to W3)
- The risk graph allow to determine the SIL requested by the process in order to keep the risk tolerable

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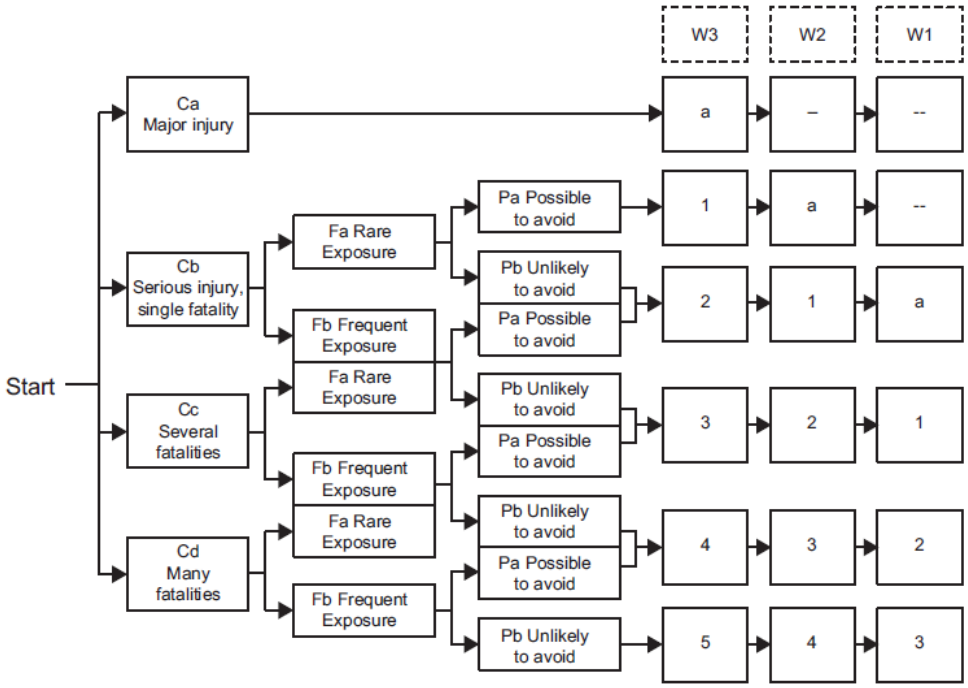

Figure 5 : graph risks analysis

LOPA

- Layer of protection analysis
- is a structured way of calculating risk reduction and SIL targets
- may be carried out as an extension to the HAZOP
- analyses more deeply the initiating events, their frequency, the consequences related to the hazard and their severities
- defines independent layers of protection and analyses their probability of failure

PHASE 2 : ALLOCATION OF SAFETY FUNCTIONS

Goal

- allocate safety function and associated integrity levels to protection layers
- used together the LOPA analysis

PHASE 3 : SAFETY REQUIREMENTS SPECIFICATION FOR THE SIS

Goal

- specify the requirements for Safety Instrumented Systems and Safety Instrumented Functions

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Requirements to be specified

- description of the SIF
- common cause failure
- safe state definition
- demand rate
- proof test intervals
- response time to bring the process in a safe state
- SIL and mode of operation (on demand or continuous)
- Process measurements and their trip point
- Process output actions and successful operation criteria
- Functional relationship between inputs and outputs
- Manual shutdown requirements
- Energizing or de-energizing to trip
- Resetting after a shutdown
- Failure modes and SIS response to failures
- Starting up and restarting the SIS
- Interfaces between the SIS and any other systems
- Application software
- Overrides/inhibits/bypasses and how they will be cleared
- Actions following a SIS fault detection
- Duty cycle and lifetime
- Environmental conditions

PHASE 4 : DESIGN AND ENGINEERING FOR THE SIS

Goal

- Enable design and engineering phase to begin
- Design the SIS in order to provide the necessary SIFs
- Realization of each SIF according to the safety requirements specification
- Calculation of the SIL related of each SIF
- Verify that the SIF design meets the specified SIL defined during the SIL determination
- Produce the functional design specifications (FDS)

Determination of the SIL of a SIF

- The SIL of a SIF expresses the probability of failure of the safety instrumented function over a certain period of time

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- The probability of failures to be considered will be different if the function is supposed to work in a demand mode or a continuous mode (see figures 3 and 4)
- The length of the period of time over which the probability has to be calculated is different for the mode on demand and the continuous mode
- The probability of failure is directly linked to failure rate of the function
- The failure rate of the function is linked to the failure rate of the components of which it consists
- The failure rate of component is linked to the MTTF/MTBF of the component
- The dangerous failure rate of a function may be lowered by using a certain architecture combining many components
- The failure rate of a function may be lowered by using on-line and off-line diagnostics

Failure rate (λ)

- Failure rate of a component : λ = F/T where F represents number of failures and T the total number of device hours (running time, miles, cycles, etc) during an investigation period for both failed and non-failed items.
- Failures can be classified in dangerous, safe and non safety related.
- The failure rate is varying over the lifetime of the system following a bathcurve : failure rate decreases at the start of life of the product and increases at the end of life (figure 6)

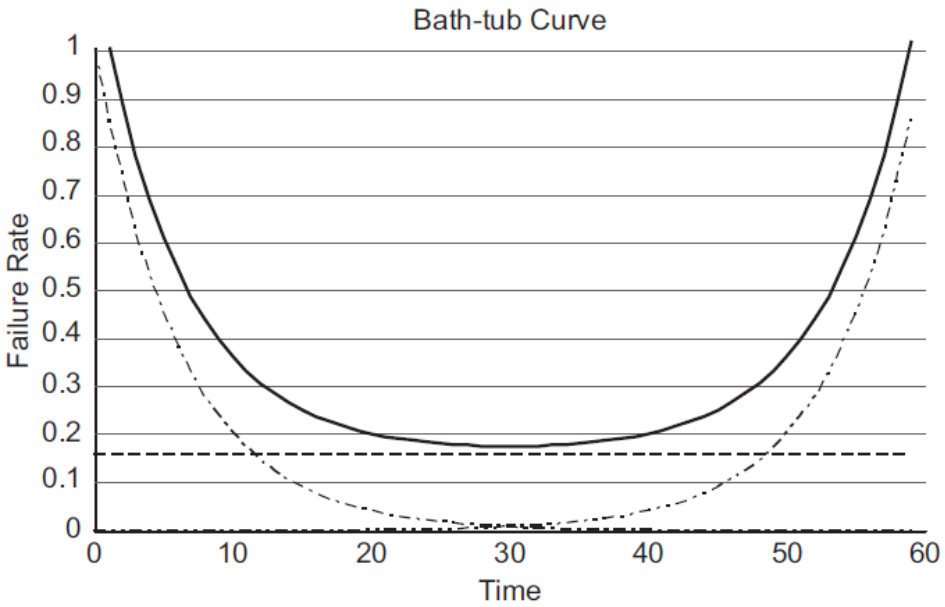

Figure 6 : bathcurve distribution showing the evolution of the failure rate

- In most of the cases, SIL calculation are made considering a constant failure rate

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- The failure rate is directly linked to the Mean Time of Failure (MTTF) and the Mean Time Between failure (MTBF) : λ = 1/MTBF, λ = 1/MTTF
- Mean Time to Dangerous Failure and failure rate may be lowered by using diagnostics tools

MTTF/MTBF

- Mean Time Between Failure / Mean Time To Failure
- MTBF refers to items that are repaired when they fail.
- MTTF refers to items that are thrown away and replaced.
- MTBF/MTTF are directly linked to the failure rate (λ) : MTBF/MTTF = 1/λ
- MTBF/MTTF determined by endurance tests, tables
- Endurance tests performed to check the lifetime of valve (number of cycles)
- Lifetime in cycles converted in years of operation gives the MTBF/MTTF

Diagnostic coverage

- SIF equipment may allow to perform self diagnostic
- Diagnostic may be performed online and off-line
- Online diagnostic is a self test operated automatically by the equipment at a regular interval of time
- Offline diagnostic is a check performed by an operator at the maintenance interval
- diagnostics allow to reduce the failure rate of the equipment
- Diagnostic coverage factor : DC = detected failure rate by diagnostic / total failure rate

PFD/PFH

- Probability dangerous failure
- The probability covers a certain period of time (1 year for PFD, 1 hour for PFH)
- The probability or dangerous failure is calculated by multiplying the dangerous failure rate by the amount period of time
- The probability of failures and type of mode of operation determine the SIL of the SIF and the SIS

Architecture

- Combining different components together allows to reduce the failure rate
- Putting 2 components in parallel (redundancy) allow to maintain the function even if one component is failing

FMEA

- Failure Mode and Effect Analysis
- Analyses the mode of failure and solution to prevent failure
- Allows to determine the systematic safety integrity of a SIF

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PHASE 5 : INSTALLATION, COMMISSIONING, VALIDATION

Goal

- Install the safety instrumented system according to the specifications and the documentation
- Commission the safety instrumented system so that it is ready for the final validation
- Validate that the safety instrumented system achieves the requirements of the safety requirement specification (SRS)

PHASE 6 : OPERATION AND MAINTENANCE

Goal

- Ensure that the required SIL of each safety instrumented function is maintained during operation and maintenance
- Operate and maintain the safety instrumented system so that the designed functional safety is maintained

PHASE 7 : MODIFICATION

Goal

- Any modification to any safety instrumented function are properly planned, reviewed and approved prior to making the change
- The required safety integrity level is maintained following any changes that may be made

PHASE 8 : DECOMMISSIONING

Goal

- Prior to decommissioning, a proper review is conducted and authorization obtained to ensure that the safety integrity is maintained during decommissioning

PHASE 9 : VERIFICATION

PHASE 10 : MANAGEMENT OF FUNCTIONAL SAFETY, FUNCTIONAL SAFETY ASSESSMENT AND AUDITING

PHASE 11 : SAFETY LIFE-CYCLE AND PLANNING

Goal

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- Identify the management activities and documentation necessary to enable the applicable lifecycle phases to be adequately addressed by those responsible
- List general requirements for management and documentation
- Specification of the responsibilities in the management of functional safety
- Specification of the responsibilities to be carried out by those with responsibilities
- Put procedures in place, implement those procedures

5. ISO 13849

5.1. SCOPE OF 13849

This standard focuses on safety components.

The standard set requirements on the following levels :
- architecture of the system
- definition of reliability data for each constituent part of the system
- diagnostic coverage of the system
- protection against common cause failures
- protection against systematic faults
- definition of parameters for evaluation of the risk

The standard produces as output a performance level.

PERFORMANCE LEVEL

- The performance level (PL) is a discrete level that specifies the ability of the safety related parts of the control system to perform a safety function.
- There are five performance levels ranked between PLa (lowest) and PLe (highest)
- In many aspects it can related to the SIL of IEC 61508/61511
- The ultimate type of data required as part of the PL determination is the PFHd (probability of dangerous failure per hour)
- This PFHd is linked to the PL and the SIL values.
- In order to assess the PL achieved by a safety related part, the following data is required for the part
  1. MTTFd (mean time to dangerous failure)
  2. DC (diagnostic coverage)
  3. architecture (category)
- Other factors must also be realized to satisfy the required PL : common cause failures, systematic failure, environment conditions and mission time
- For a single channel architecture, MTTFd = 1/PFHd

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PL (Performance Level)	PFH_D (Probability of dangerous failure per hour)	SIL (Safety Integrity Level)
a	$\geq 10^{-5}$ to $<10^{-4}$	None
b	$\geq 3 \times 10^{-6}$ to $<10^{-5}$	1
c	$\geq 10^{-6}$ to $<3 \times 10^{-6}$	1
d	$\geq 10^{-7}$ to $<10^{-6}$	2
e	$\geq 10^{-8}$ to $<10^{-7}$	3

Figure 7 : correspondence of PL, SIL, and probability of dangerous failure per hour

REQUIRED PERFORMANCE LEVEL

- The performance level is normally used to identify the level of safety of components
- It may also be used to identify the performance level required by an application
- The method that is used is the risk graph analysis
- Information required to determine the required performance level :
  1. the severity of potential injury (S)
  2. the frequency of exposure (F)
  3. the probability of injury (P)

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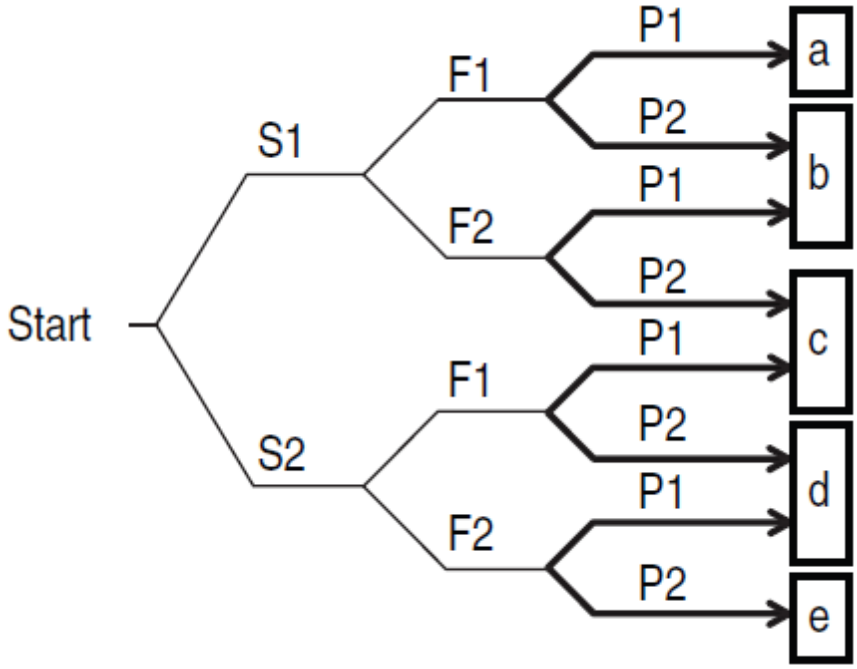

Figure 8 : risk graph analysis

ARCHITECTURE OF THE SYSTEM

Any safety related system may be considered as consisting of 3 elements :

- input device
- logic unit
- output device

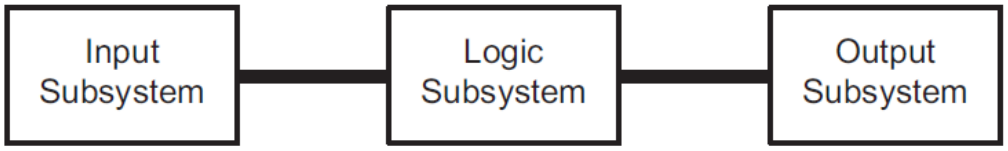

Figure 9 : safety related system

There are many different ways to combine all those elements together.
Each of them will allow to reach different levels of safety.
ISO 13849 standard specifies 5 categories called Designated Architecture Categories.
They can be applied either to a complete system or a subsystem.

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Designated Architecture Category B (Figure 9)

- 1 input device – 1 logic unit – 1 output device with single connection between all 3 units
- This is called a single channel architecture
- The system can fail in the event of a single fault
- This is the level with the lowest reliability

Designated Architecture Category 1 (Figure 9)

- Designated Architecture Category 1 has the same structure as Category B
- uses well tried safety principles
- system can still fail in the event of a single fault but its occurrence is lower.

Designated Architecture Category 2 (Figure 10)

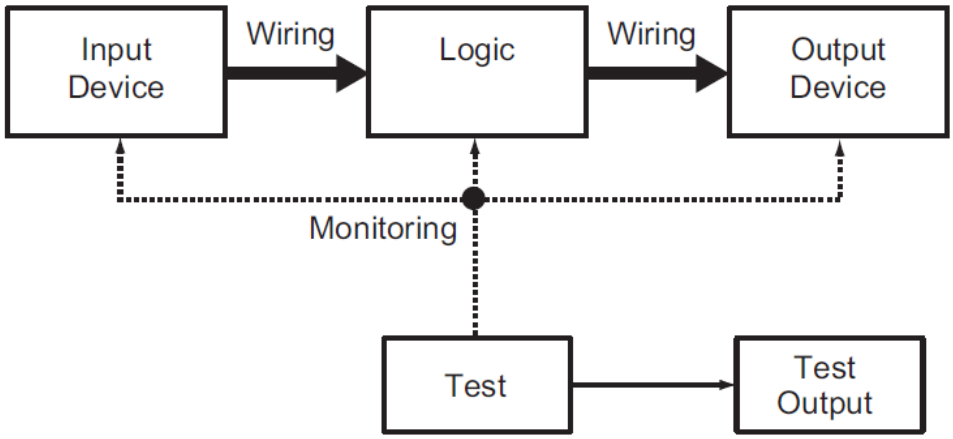

Figure 10 : Designated Architecture Category 2

- involves a diagnostic monitoring via a functional test of the system or subsystem
- This diagnostic must automatically occur at start up and then periodically with a frequency that equates to at least one hundred tests to every demand on the safety function.

Designated Architecture Category 3 (Figure 11)

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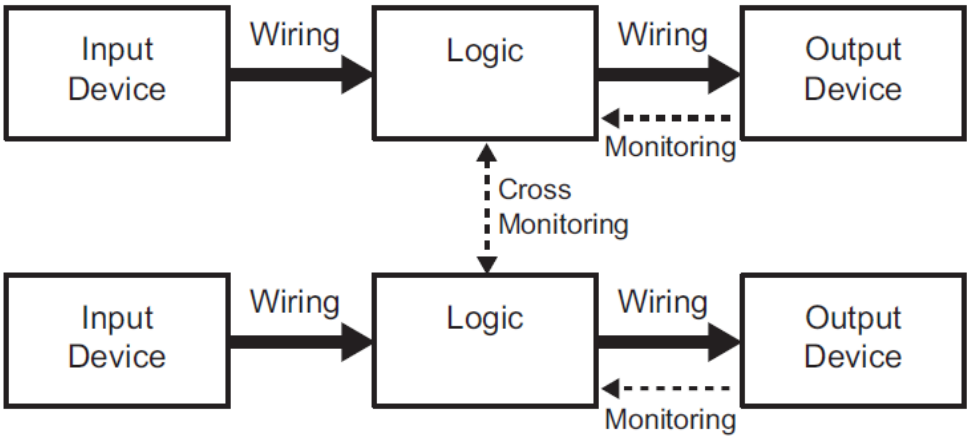

Figure 11 : designated architecture category 3

- the system may not fail in the event of a single fault : single fault tolerance.
- the most common way to achieve this is to employ a dual channel architecture.
- The single fault has also to be detected.

Designated Architecture Category 4 (Figure 12)

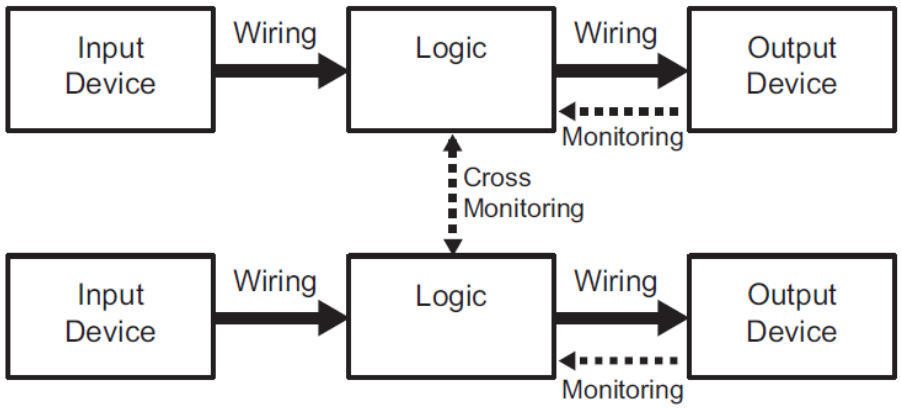

Figure 12 : designated architecture category 4

- Designated Architecture Category 4 has similar requirements to category 3 but it requests greater monitoring i. e. higher diagnostic coverage (at least 99 % with Category 4)

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MEAN TIME BETWEEN DANGEROUS FAILURES/TO DANGEROUS FAILURES (MTBFd/MTTFd)

- Average mean time before the occurrence of a failure that could lead to the failure of the safety function
- It is expressed in year
- Mean time between failure (MTBF) is used for component that can be repaired
- Mean time to failure (MTTF) is used for components that are not repairable
- It is average value of the MTTF/MTTF of each component on each channel and can be applied either to a system or a subsystem
- MTTFd is combined to the designated architecture category and the diagnostic coverage (DC) to provide a preliminary PL rating.

DETERMINATION OF PFH AND MTBF/MTTF

- Uses a technics called mechanistic technology
- Failure is proportional to both the inherent reliability and the usage rate.
- The estimation of PFH and MTTFd values is done by a test process known as B10d testing according to ISO 13849.
- In the B10d test, a number of device samples (usually at least 10) are tested under suitably representative conditions. The mean number of operating cycles achieved before 10% of the samples fail to the dangerous condition is known as the B10d value.

DIAGNOSTIC COVERAGE

- The term Diagnostic Coverage (DC) is used to characterize the effectiveness of a diagnostic testing to check whether the safety function is still working.
- The symbol λ is used for failure rate.
- DC expresses the relationship of the rates of occurrence of the 2 following types of dangerous failure :
  1. dangerous detected failure (λdd) : failures that would cause, or could lead to, a loss of the safety function, but which are detected. After detection, a fault reaction function causes the device or system to go to safe state.
  2. dangerous failure (λd) : all those failures that could potentially cause, or lead to, a loss of the safety function. This includes both the failures that are detected and those that are not.
- DC is expressed by the formula : DC = λdd/λd
- DC is divided in 4 basic ranges :
  1. < 60% = none

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2. 60 % to < 90% = low
3. 90 % to < 99 % = medium

RELIABILITY DATA

- ISO 13849 uses quantitative reliability data as part of the calculation of the PL achieved by the safety related parts of a control system.
- Data may come from recognized reliability handbooks but the preferred source is the manufacturer.
- The ultimate type of data required as part of the PL determination is the PFHd (probability of dangerous failure per hour)

SYSTEMATIC FAULTS

- Failures that appear to be random in nature.
- Types of failures collectively known as “systematic failure” that can be attributed to errors committed in the design or manufacturing process.
- In order to reduce the occurrence of those cases of failures, a FMEA (Failure mode analysis) will be performed on the system.
- FMEA lists all parts inside of the system and checks :
  1. how parts have been designed (drawing, lifetime test)
  2. how parts have been assembled (assembly instruction)
  3. experience on the field

MISSION TIME

- Maximum period of time during which the safety related system is supposed to be used.
- Afer this period, the component has to be replaced.

COMMON CAUSE FAILURE

- In most dual channel systems or subsystems the diagnostic principle is base on the premise that there will not be dangerous of both channels at the same time or within the diagnostic test interval.
- It is also possible that an event that causes one component to fail may also cause the failure of other components.
- This is termed “common cause failure” normally abbreviated as CCF.
- The degree of propensity for CCF is normally described as the β factor

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6. PRODUCT DESCRIPTION

The purpose of the 3/2 way solenoid valves of the series 52, 54 and 67 is to ensure inlet pressure when energized and exhaust when de-energized. The safety function of a single device consists of a failsafe closing (NC) by an air and mechanical spring force when the electrical signal is turned off. The valve is a pilot operated valve with external pilot pressure.

Assembled on a manifold, the solenoid valves operate as a redundant valves package (see Figure 1). The integrated porting (PS1 and PS2) allows the connection of pressure switches for pressure detection (see Figure 14). The safety function of the redundant system consists of a failsafe closing (function-to-vent) by spring force with supply isolated.

The solenoid valves can be used either as a single device or as a redundant manifold assembly (Figure 13).

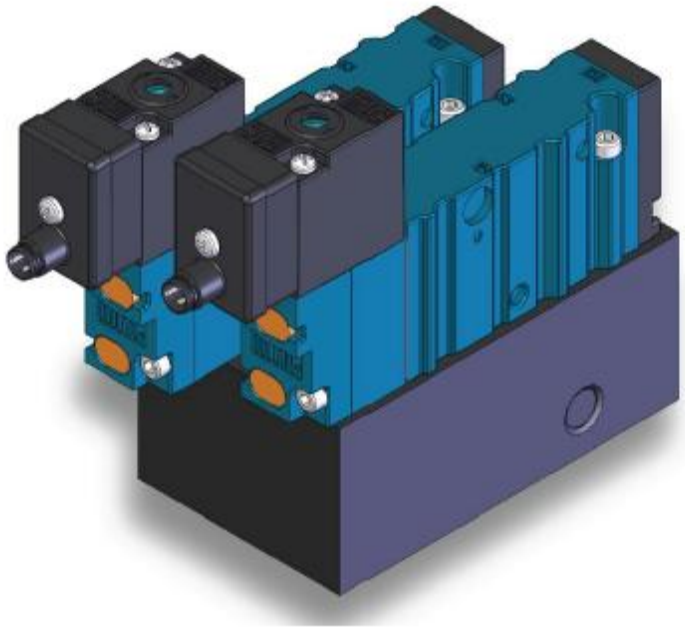

Figure 13 : MAC redundant assembly 52 series valves

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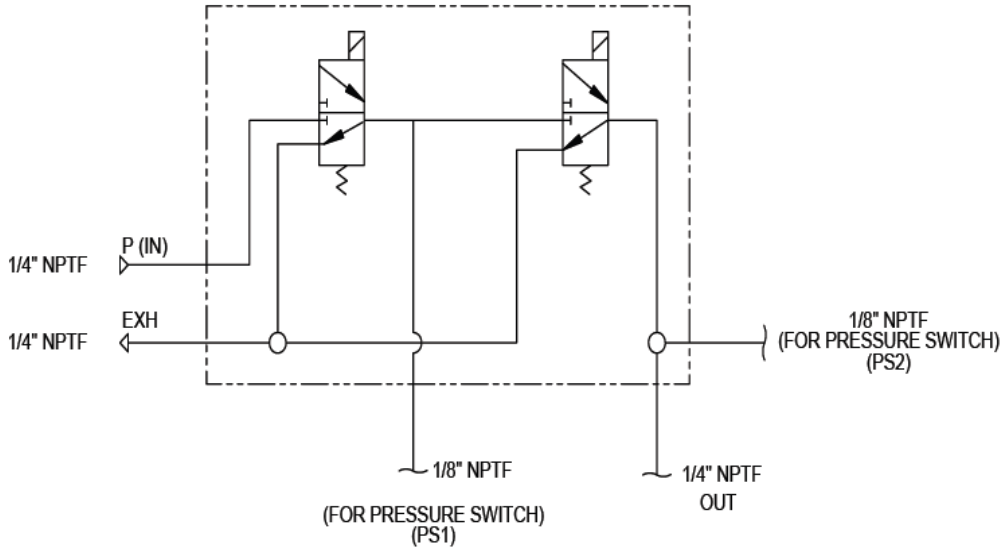

Figure 14 : pneumatic diagram redundant assembly and porting

7. FUNCTIONAL SAFETY RELEVANT SPECIFICATIONS

7.1 DEFINITION OF SAFETY FUNCTION

The solenoid valves are deployed in safety-related systems and are used to ensure redundancy of inlet pressure and exhaust. The safety function of the test item consists of a failsafe closing (function-to-vent) by an air and mechanical spring force with supply isolated.
Valve closes the main inlet and exhausts the cylinder port when turning off the electrical signal.
The valve has short de-energization response times generated by an air and mechanical spring that allow a quick and safe exhaust.

7.2 ENVIRONMENTAL LIMITS

- Outside temperature : from 0 to + 50°C
- Humidity : up to 100 % relative
- Washdown protection rate : IP 65

7.3 APPLICATION LIMITS

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- Fluid : air or inert gases
- Lubrication compressed air : not required but if used, a medium aniline point (80 to 100°C) is recommended
- Air preparation according to ISO 8573 (class preparation 743) :
  1. particles : size < 40µ and maximum concentration between 5 and 10 mg/m³
  2. dew point : < + 3°C with ambient temperature of 20°C
  3. oil concentration : < 1 mg/m³
- Voltage electrical signal : nominal voltage -15%/+10%
- Continuous duty
- Main pressure : vacuum to 8.0 Bar
- External pilot pressure : from 2.1 to 8.0 Bar

7.4 DESIGN VERIFICATION

The FMEA conducted during the assessment by the TÜV Rheinland and the measures documented in the FMEA of the design are a suitable proof that the design processes of the test item are sufficient to fulfill the requirements for basic and well-tried safety principles.
Together with the quality control methods documented in the FMEA (especially the factory acceptance test) , the manufacturing process of the test item is in the opinion of the Test Centre (Report N° V467.01/14 TÜV Rheinland) sufficient to produce components suitable for safety related systems category B, 1 – 4 in accordance with DIN EN ISO 13849

7.5 SIL/PL CAPABILITY

The solenoid valves are suitable for use in safety-related systems in the demand type with a high rate of demand in accordance with IEC 61508 up to and including SIL2 with a hardware fault tolerance of HFT = 0 and up to and including SIL3 with a minimum hardware fault tolerance of HFT = 1 (see Report N°V467.01/14 TÜV Rheinland).

The solenoid valves are suitable for use in safety-related systems of category B, 1 – 4 in accordance with DIN EN ISO 13849 up to and including PL d with a hardware fault tolerance of HFT = 0 and up to and including PL e with a minimum hardware fault tolerance of HFT = 1 (see Report N°V467.01/14 TÜV Rheinland).

The test result refers only to the inspected solenoid valves. The test results do not represent any statement with regard to the safety integrity (SIL) and performance level (PL) of the test object on an

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application. The suitability for certain applications can only be realized through the evaluation of the respective safety-related overall system in which the test item is used, including all safety-related components in accordance with IEC 61508 and DIN EN ISO 13849.

7.5.1 SYSTEMATIC INTEGRITY

The FMEA of the solenoid valves performed as part of the inspection has shown that the failure behavior of all components deployed is sufficient defined.
Based on the documentation and analysis of the solenoid valves failure modes in the FMEA and the test results of the device, the system is at present classified as type A in accordance with IEC 64508-2, section 7.4.4.1.2.

7.5.2 MODE OF OPERATION

The operation mode of the test item can be classified as an operation mode with a high rate of demand (high demand mode) in accordance with IEC 61508-4, section 3.5.16.

7.5.3 DIAGNOSTIC COVERAGE DC

The solenoid valve itself does not contain any diagnostic measures. If diagnosis is required for the safety function of the test item, then this must be provided through external measures, for example pressure switch, as part of the safety-related overall system.

7.5.4 HARDWARE FAULT TOLERANCE

The solenoid valve is a redundant system and consequently itself has a hardware fault tolerance of HFT = 1. As a single channel device, the test item has a hardware fault tolerance of HFT = 0. If a hardware fault tolerance of the whole final elements is necessary then a multichannel structure of the safety-related overall system has to be stipulated as required.

7.5.5 SAFE FAILURE FRACTION

The safe failure fraction (SFF) states the ratio of safe failures of the safety function of a component to all possible failures of the safety function of the component. Safe failure of the safety function is a failure that does not lead to a dangerous situation or that can be detected before a dangerous situation arises.

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The safe failure fraction of the test item was estimated through the ratio of faults identified in the FMEA.

7.5.6 SAFETY PARAMETERS

Series			**52 / 54**	**67**
B_{10d} value	B_{10d}	[-]	10 500 000	5 500 000
Internal Hardware Fault Tolerance	HFT_{int}	[-]	1	
Safe Failure Fraction per internal channel	SFF	[%]	60 - < 90	
Diagnostic Coverage	DC	[-]	0	
Common Cause Factor	β_{int} [1]	[%]	10	
Type of Subsystem Acc. IEC 61508-2, 7.4.4.1.3		[-]	Type A	
Mode of Operation Acc. IEC 61508-4, 3.5.16		[-]	High and Low Demand Mode	
Dangerous Failure Rate	λ_D	[1/h]	See below	
Low Demand Mode				
Probability of Dangerous Failure on Demand	PFD_{avg}	[-]	4.65 E-05	
Assumed Test Interval	T_i	[y]	1	
Assumed demand frequency	n_{op}	[1/y]	1	
High Demand Mode				
Probability of Dangerous Failure per hour	PFH_D	[1/h]	See below	
Mean Time to Dangerous Failure	$MTTF_D$	[h]	See below	

[1] The Common Cause Factor is always to be examined taking into consideration the safety-related overall system with regard to the certain application.

SINGLE DEVICE

Valve series	**52 /54**	**67**

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MTTFd	12470 year	6752 year
λd (1/h)	9.15 E-09	1.69 E-08

REDUNDANT ASSEMBLY

Valve series	**52 /54**	**67**
MTTFd	124623 year	67547 year
λd (1/h)	9.16 E-10	1.69 E-09

8. INSTALLATION AND COMMISSIONING

8.1 INSTALLATION

- MAC valves are intended for use in industrial pneumatic systems
- MAC valves are only a component of an overall system
- MAC valves are not designed nor intended to be used to operate and/or control the operation of clutch and/or brake systems on power presses.
- Do not install MAC valves on a machine without turning off air (bleed system completely) and electricity to the machine.
- MAC valves should only be installed by qualified, knowledgeable personnel who understand how the specific valve is to be pneumatically piped and electrically connected.
- Flow paths through the valve are shown in the technical description and on the valve by use of ANSI or ISO type standard graphic symbols. Do not install unless these symbols and the valve functions and operations are thoroughly understood.
- For specifications on the conditions of use, please refer to points 6 and 7 of the present manual and the MAC catalog
- Do not operate outside of pressure range listed on valve label
- Air supply must be clean, contamination of valve can affect proper operation
- If airline lubrication is used, consult present manual, catalog, parts and operation sheet, or factory for recommended lubricants
- MAC valves are to be installed only on application that meet all operating specifications described in the present manual and MAC catalog

9. OPERATION AND MAINTENANCE

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9.1 GENERAL REQUIREMENTS

- MAC valves should only be serviced by the local distributor and/or the factory
- Do not remove from service any MAC valve without first shutting off both the air and electricity to the valve and making certain no pressurized air which could present a hazard is retained in the system
- MAC valves should be removed from service by qualified , knowledgeable personnel who understand how the specific valve is piped and used and whether there is air retained in the connecting lines to the valve or electric power still connected to the valve
- Do not subject MAC valves parts to any foreign substance including lubricants and cleaning agents not specifically recommended by MAC Valves
- MAC valves are never to be stepped on while working on a machine. Damage to the valve, or lines to the valve (either air or electrical lines) could result in dangerous situation
- Any maintenance outcome has to be recorded in the company SIF inspection database

9.2 PROOF TEST STEPS

Step	Action
1	Bypass the safety function and take appropriate action to avoid a false trip
2	Turn off the electrical signal to the valve in order to force the valve to perform a full stroke to the failsafe state and confirm that the safe state was achieved within the correct time.
3	Turn off the main air and the pilot air supplies to the valve
4	Remove the valve from the installation
5	Inspect the valve for damages, internal and external contamination
7	If damages and/or contamination, remove the valve and replace by a new one
8	Connect the valve to main air and external pilot air supplies
9	Check valve on leakage in the not energized position
10	Operate valve electrically and check leakage in energized position

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11	Record the test result and the failures in the company SIF inspection database
12	Remove the bypass and restore normal operation.

9.3 PROOF TEST WITHOUT AUTOMATIC TESTING

The objective of proof testing is to detect failures within the valve that are not detected by any automatic diagnostics of the system. The main concerns are undetected failures that prevent the safety instrumented function from performing its intended function.

The frequency of proof testing, or the proof test interval, is to be determined in reliability calculations for the safety instrumented functions for which a valve is applied. The proof tests must be performed more frequently than or as frequently as specified in the calculation in order to maintain the required safety integrity level of the safety instrumented function.

A proof test as specified at point 9.1 is recommended. The results of the proof test should be recorded and any failures that are detected and that compromise functional safety should be reported to MAC valves.

Trained personnel, performing the proof test of the valve, should be trained in SIS operations, including bypass procedures, valve maintenance and company Management of Change procedures.

9.4 USEFUL LIFETIME

The test statement is valid for new valves for a period of time of 5 years after commissioning plus 1.5 year storage time. The maximum cycle lifetime is limited to the B10d value of the test item (10 millions of cycles for the series 52 and 54, 5 millions of cycles for the series 67). The test statement presupposes that during this period of time the valves are maintained and operated in accordance with the manufacturer's specifications.

9.5 MANUFACTURER NOTIFICATION

- Any failures that are detected and that compromise functional safety should be reported to MAC Valves.
- Please contact MAC Valves or its local distributor

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- Failing valves have to be returned to MAC valves for deeper analysis following the MAC procedure for valves returned

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MADE BY	REVISION B	RECEIVER	DATE

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