



Table LF010-1/E

Fluid contamination

Fluid contamination defines the presence of foreign particles and substances into the hydraulic fluid, classified in 3 families (solid, water and air contamination), which produce different effects on hydraulic components.

This aspect is a main issue for all hydraulic systems, being responsible for failures and increased machine downtime with consequent heavy costs for end users.

The purpose of this document is to provide general information about type, sources and effects of fluid contamination on hydraulic components.

In particular it is focused on the solid contamination, most commonly present in hydraulic systems, with a description of international methods for its measurement and classification.

1 SOLID CONTAMINATION

It is responsible for wearing and damages of hydraulic components causing approximately 80% of hydraulic systems failures.

Solid contaminants can enter into the hydraulic system from the external environment or they can be generated during the system operation. A detailed analysis about the potential causes of fluid contamination is described in section 4

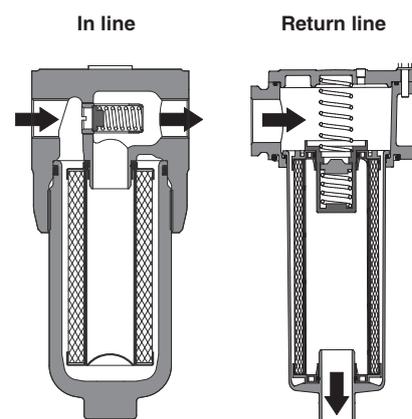
Effects: solid contamination causes accelerated wear and sticking phenomena, with consequent increased internal leakages and inaccurate regulation of hydraulic components. In the worst cases it may lead to the components breakage.

A detailed analysis of the effects of solid contamination on hydraulic components is described in section 5

Removal methods: the solid contamination cannot be completely removed but it can be consistently reduced at acceptable levels by means of **hydraulic filters (in line and return line type)**.

Contamination coming from external environment can be also prevented using specific air filters and pressurized tanks.

An extensive description of filter types, contamination classes and suggested filtration circuits is described in the technical table LF020



2 WATER CONTAMINATION

Water can be present into the hydraulic fluid as dissolved water (emulsion) or free water, depending to its concentration and fluid temperature.

Water can enter into the hydraulic system during oil filling operations, through the tank cover or by the air moisture present in the ambient.

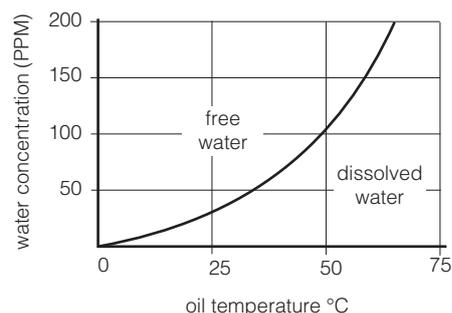
Effects: water contamination causes oxidation and corrosion of metal parts, plus alteration of chemical proprieties of the hydraulic fluid.

Removal methods: sealed tanks are normally used in case of system out-doors installation to prevent water dropping.

Centrifugal separators are a valid solution to remove the water emulsion from the hydraulic fluid.

Breather filters are normally used to remove the humidity form the air entering the oil tank.

Note: consult Atos Technical Office for detailed information about water contamination removal



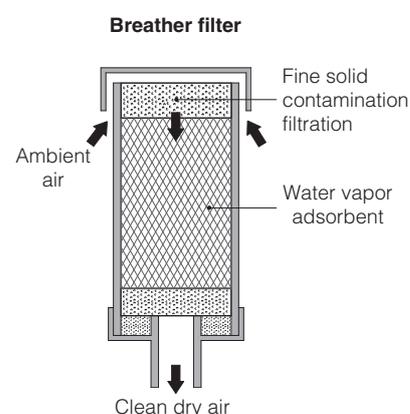
3 AIR CONTAMINATION

Air is always present into the hydraulic system before its commissioning, or it can be introduced during maintenance.

Effects: the presence of air may cause pumps damage due to cavitation, inaccurate valve regulation and vibrations.

Removal methods: air bleeding points are normally present in the upper side of the hydraulic system and in hydraulic components. The complete air bleeding procedure must be performed at the system commissioning of after maintenance operations.

Note: consult Atos Technical Office for detailed information about air bleeding procedures. See also www.atos.com, tech. table P002 for system commissioning



4 SOURCES OF SOLID CONTAMINATION

The solid contamination has two main sources:

- **Fluid original contamination**, caused by poor quality hydraulic fluids, or fluids stored in dirty tanks
- **System progressive contamination**, generated during the system working and caused by wearing of metal parts and rubber pipes

In a more detailed analysis, following causes of contamination can be identified:

4.1 First fluid filling

Oil coming from shipping containers usually has a contamination level higher than the standards acceptable for most hydraulic systems: oil cannot be assumed to be clean unless it has been carefully filtered.

4.2 Built-in contamination

Different contaminants can be found in new systems and they can be directly related to manufacturing and assembling operations.

4.3 Self-generated contamination

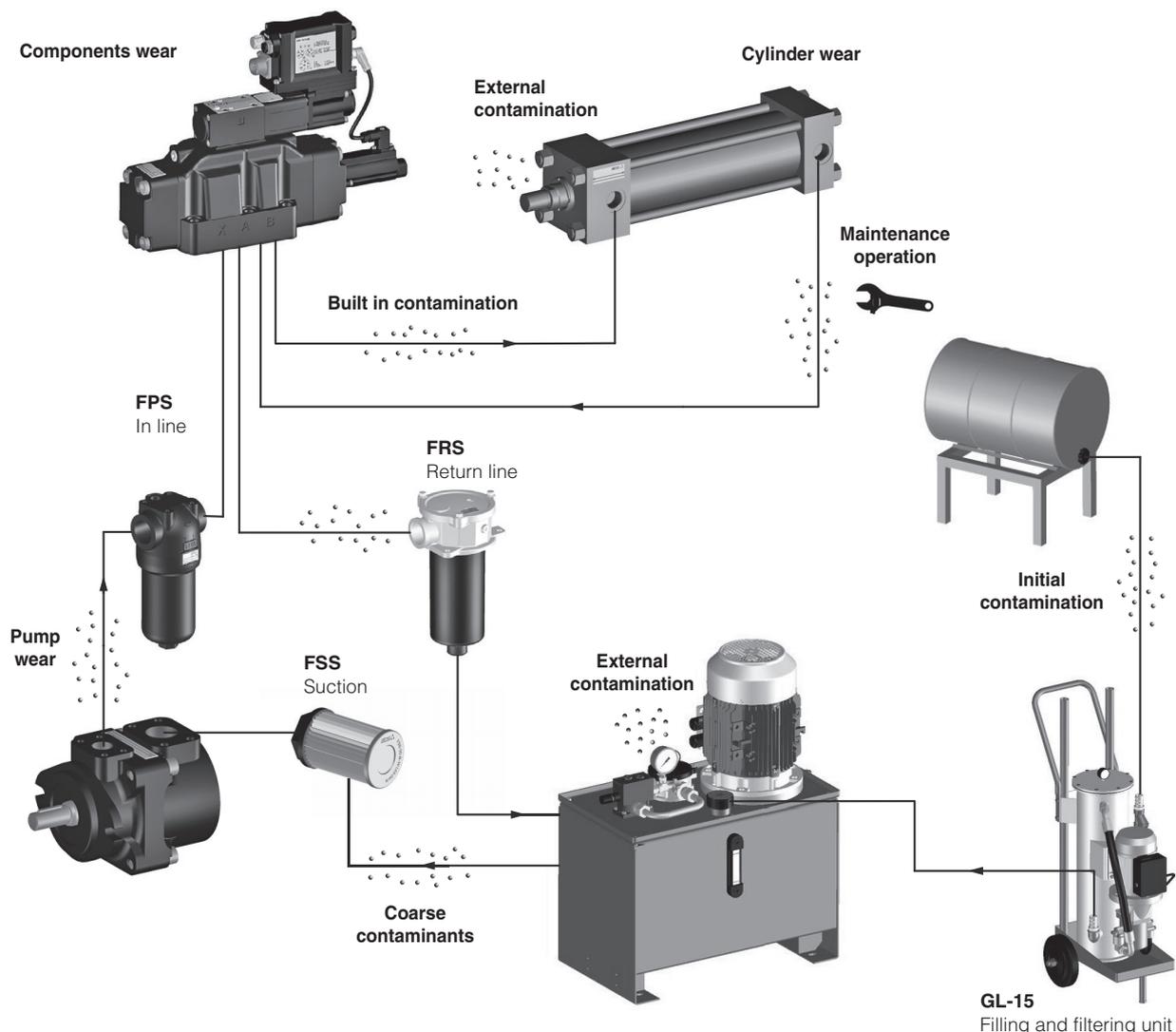
The major source of contamination directly comes from the normal hydraulic system operation. Most of contaminant are due to rubber released from the inner walls of flexible hoses, some from with moving parts of hydraulic components, like pumps and valves

4.4 External contamination

Contaminants coming from the surrounding environment can enter the hydraulic fluid through reservoir breather caps and worn cylinder rod seals.

4.5 Maintenance-induced contamination

Contaminants coming from the surrounding environment can enter the system during maintenance operations. Inaccurate cleaning of the pipes after the replacement of failed components can be the source of further contamination.



5 EFFECTS OF SOLID CONTAMINATION

The presence of solid contaminants into the hydraulic fluid have harmful effects on the correct operation and service life of hydraulic components as pumps, valves and actuators.

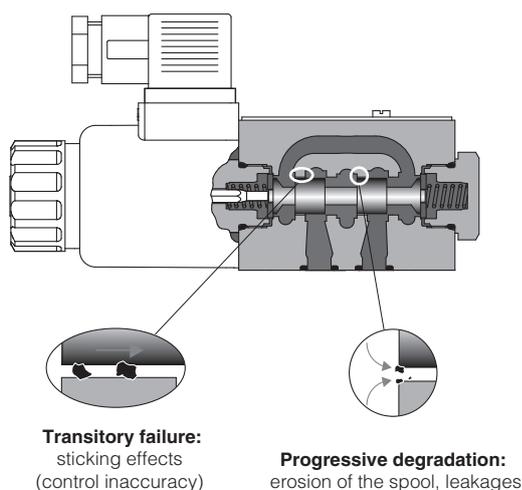
They mainly cause abrasion, erosion and fatigue effects on components surface with following main consequences:

- increased internal leakages
- sticking effects
- permanent wear of moving parts

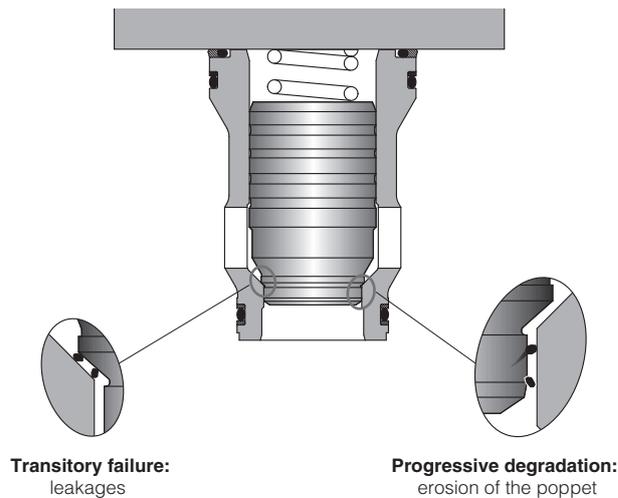
Typical failures produced by solid contamination can be classified as:

- **Transitory failures**, when particles enter components causing its temporarily malfunction. The components returns to correctly operate as soon the particles are removed by the oil flow.
- **Progressive deterioration**, when particles cause micro-erosion and abrasion of the component surfaces. This failure causes a progressive degradation of performances until the functionality of the component is definitively compromised.
- **Irreparable failure**, when particles enter the gap between mobile parts causing the sudden sticking. This failure could be solved by cleaning the internal parts of the component, in the worst cases the whole components must be replaced

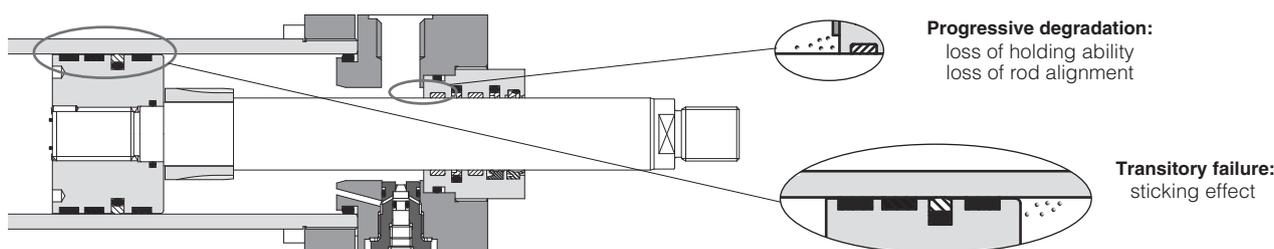
Typical failures in spool valve



Typical failures in poppet cartridges



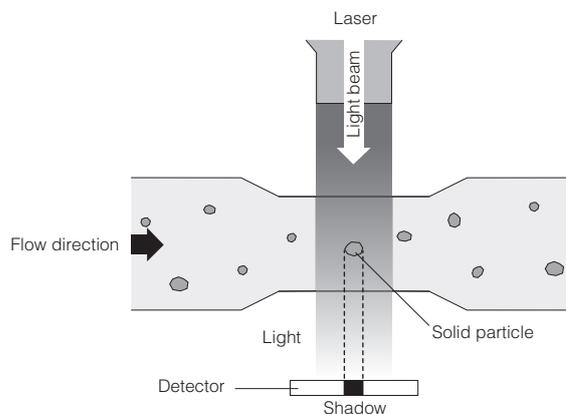
Typical failures in cylinders



6 MEASUREMENT OF SOLID CONTAMINATION

One of the most common methods used by the industry for solid contamination analysis is the Automatic Particles Counter (APC). It is based on the principle of a light beam projected through the sample of fluid to be analyzed.

As a solid particle passes through the light beam, it results in a measurable energy drop that is proportional to the size of the particle. This method permits to measure the quantity and dimensions of solid particles present in the fluid and it is used for the classification of the fluid contamination level, as described in section 5



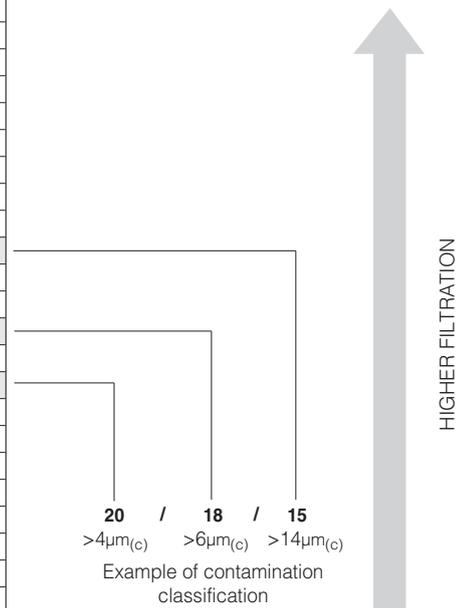
7 CLASSIFICATION OF CONTAMINATION LEVEL

The contamination level identifies the quantity and dimensions of solid particles present into the hydraulic fluid. It is classified according to the European standard ISO 4406/1999, while for North America it is classified by SAE AS 4059 or NAS 1638 standards.

7.1 ISO 4406 classification

ISO 4406 is the European standard being used extensively within the industrial hydraulics to measure and classify the fluid contamination. The contamination level is measured by counting the number of particles of a certain dimension present into a 100 ml of fluid. It is expressed by a combination of 3 codes, i.e: **20 / 18 / 15**, respectively identifying the quantity of contaminants with dimension > 4 μm(c), > 6 μm(c) and > 14 μm(c), as per following table

ISO CODE (to ISO 4406)	Particle quantity / 100 ml	
	from	to
5	16	32
6	32	64
7	64	130
8	130	250
9	250	500
10	500	1.000
11	1.000	2.000
12	2.000	4.000
13	4.000	8.000
14	8.000	16.000
15	16.000	32.000
16	32.000	64.000
17	64.000	130.000
18	130.000	260.000
19	260.000	500.000
20	500.000	1.000.000
21	1.000.000	2.000.000
22	2.000.000	4.000.000
23	4.000.000	8.000.000
24	8.000.000	16.000.000
25	16.000.000	32.000.000
26	32.000.000	64.000.000
27	64.000.000	130.000.000
28	130.000.000	250.000.000



7.2 SAE AS 4059 classification

This classification is normally adopted in North America, particularly in aerospace industry. The contamination level is classified by a combination of 3 codes, i.e. **7B/6C/5D** identifying the quantity of contaminants of a certain dimension present into 100 ml of fluid

Dimensions code		A	B	C	D	E	F
Particle dimensions		> 4 μm(c)	> 6 μm(c)	> 14 μm(c)	> 21 μm(c)	> 38 μm(c)	> 70 μm(c)
		Particle quantity /100 ml					
Contamination classes	000	195	76	14	3	1	0
	00	390	152	27	5	1	0
	0	780	304	54	10	2	0
	1	1.560	609	109	20	4	1
	2	3.120	1.220	217	39	7	1
	3	6.250	2.430	432	76	13	2
	4	12.500	4.860	864	152	26	4
	5	25.000	9.730	1.730	306	53	8
	6	50.000	19.500	3.460	612	106	16
	7	100.000	38.900	6.920	1.220	212	32
	8	200.000	77.900	13.900	2.450	424	64
	9	400.000	156.000	27.700	4.900	848	128
	10	800.000	311.000	55.400	9.800	1.700	256
11	1.600.000	623.000	111.000	19.600	3.390	1.020	
12	3.200.000	1.250.000	222.000	39.200	6.780		



7.3 NAS 1638 classification

NAS 1638 (National Aerospace Standard) is a type of classification used in North America.

It divides the dimensional distribution of the particles into intervals (5-15 μm, 15-25 μm, etc.) and assigns a code to each interval, according to the following table in which is reported also a comparison with ISO 4406 and SAE AS 4059 standards.

ISO 4406	SAE AS 4059	NAS 1638
14/12/09	4A/3B/3C	3
15/13/10	5A/4B/4C	4
16/14/11	6A/5B/5C	5
17/15/12	7A/6B/6C	6
18/16/13	8A/7B/7C	7
19/17/14	9A/8B/8C	8
20/18/15	10A/9B/9C	9
21/19/16	11A/10B/10C	10
22/20/17	12A/11B/11C	11
23/21/18	13A/12B/12C	12





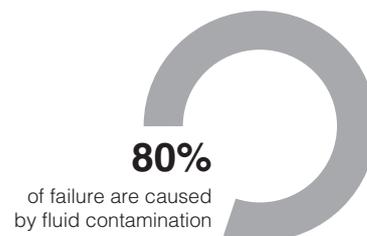
Table LF020-2/E

Filtration guidelines

Cleanliness of hydraulic fluid is a priority aspect in the design of all hydraulic systems as approximately 80% of failures are caused by the presence of solid contamination.

The solid contamination cannot be completely removed, but it can be consistently reduced and controlled by means of hydraulic filters (in line and return line type, see section 2) so that the quantity and dimensions of particles present into the fluid (contamination class) are acceptable for the specific type of system.

The purpose of this document is to provide information on the different types of filters and suggestions for their correct use. Through an optimized filtration system it is possible to obtain appropriate fluid cleanliness and thus reduce the damages caused by contamination, extending the life of the machines and preventing production downtime.



1 RECOMMENDED CONTAMINATION CLASSES

The **recommended fluid contamination class** is the max level of contamination acceptable for a certain hydraulic system and it depends to the filtration system architecture.

The fluid contamination class must be evaluated taking into account several parameters as:

- type of hydraulic components installed in the system: the required cleanliness level has to be determined according to the most sensitive component, i.e. presence of servoproportional valves
- type of application and surrounding environment: particular dusty environments, i.e. ceramic presses, require specific filtration circuits and methods to prevent that the solid contamination enters the system tank (pressurized tank)
- duty cycle: heavy duties and high pressure values require better contamination classes
- expected system lifetime
- typical operation and start-up temperatures

The fluid contamination level of a specific hydraulic system corresponds to the contaminant level measured in the tank.

The following table provides the suggested contamination classes, depending on the hydraulic components and their expected operating life. The contamination class has to be selected according to the most sensitive component installed in the system.

Standard	Typical contamination classes						
	15/13/10	16/14/11	17/15/12	18/16/13	19/17/14	20/18/15	21/19/16
ISO 4406	15/13/10	16/14/11	17/15/12	18/16/13	19/17/14	20/18/15	21/19/16
NAS 1638	4	5	6	7	8	9	10
SAE 5049	5A/4B/4C	6A/5B/5C	7A/6B/6C	8A/7B/7C	9A/8B/8C	10A/9B/9C	11A/10B/10C
Recommended filter element	F03	F03 F06	F06	F06 F10	F10 F20	F20 F25	
Component							
Proportional valves		longer life		normal operation			
Solenoid & conventional valves					longer life	normal operation	
Variable displacement pumps				longer life		normal operation	
Fixed displacement pumps					longer life		normal operation
Cylinders					longer life	normal operation	

2 HYDRAULIC FILTERS TYPE

The architecture of a filtration system involves the use of different type of hydraulic filters with specific characteristics; typically they are "in line" and "return line" filters.

The type of fluid used in the hydraulic system influences the choice of filter.

It is always recommended to verify the compatibility of the fluid characteristics with the selected filter.

2.1 In line filters

In line filters are normally installed in the system main line, immediately after the pump or before valve's manifold, in order to protect all downstream components from contamination.

They have to be sized in accordance with the maximum system pressure and flow rate.

Atos in line filters **FPS** (threaded ports) and **FPH** (SAE 6000 flanged ports) are suitable for max operating pressure up to 420 bar.

In line filters are provided with or without by-pass valve:

- filters with by-pass valve are used to permit the flow passage in case of clogged filtering element. This is an extreme condition to be always avoided by a correct maintenance
- filters without by-pass valves are used to protect critical components like servoproportional valves; in this execution the filter element can withstand a higher differential pressure (collapse pressure)

In line filters can be provided with a clogging indicator, notifying the status of the filter element and allowing its replacement before the filter by-pass opening (if present), see section 6.



FPS



FPH



FRS



FSS

2.2 Return line filters

They perform the **filtration of the fluid returning back to the tank from the hydraulic circuit**, ensuring that all the contaminants generated by components wear do not enter the tank and will not be recirculated into the system.

They have to be sized considering the maximum flow on return line during the whole machine cycle; particularly, in case of differential cylinders the return flow could be greater than the pump flow.

Return line filters can be installed in line or on the top of the hydraulic tank and have to be selected considering return line pressure.

Atos return line filters type **FRS** are designed for tank top mounting and to withstand max operating pressure up to 8 bar.

Return line filters are provided with a by-pass valve to prevent dangerous excessive back-pressure in the return line caused by the clogged filter element.

The filter outlet must be always located below the fluid level, in all operating conditions, to prevent possible foaming of the fluid in the tank.

2.3 Suction filters

These filters are used to **protect the pump from ingestion of coarse contamination**. Atos suction filters type **FSS** are designed to be directly fit on the pumps suction line.

To avoid the risk of pump cavitation, suction filters are generously sized, with high filtration ratings and low differential pressures.

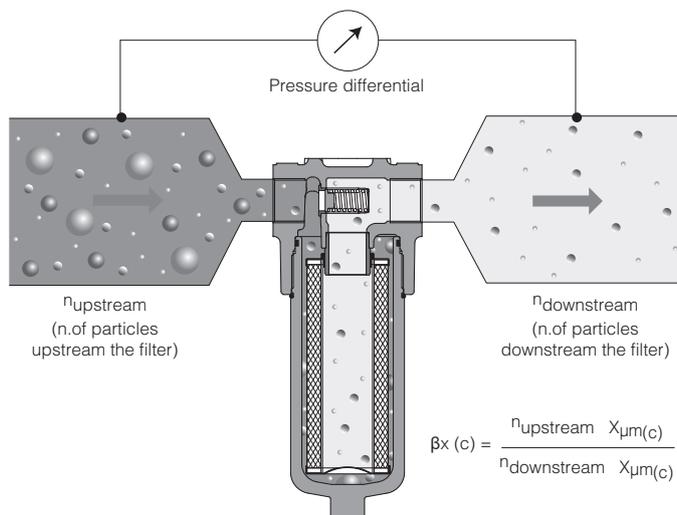
Suction filters have to be sized also considering cold start-up operations, because low oil temperatures could boost up cavitation phenomenon.

Due to cavitation reasons they are normally avoided for variable displacement piston pumps.

3 FILTER EFFICIENCY AND BETA RATIO

The filter efficiency is the capability of the filter to block a certain quantity of particles equal or greater than a defined dimension.

The most commonly used rating in the industry is the **Beta ratio $\beta_x(c)$** , defined as the number of particles of a given size upstream the filter, divided by the number of particles of the same size counted downstream the filter. The higher the Beta Ratio, the higher is the filter efficiency.



$$Efficiency\% = 100 \frac{\beta_x(c) - 1}{\beta_x(c)}$$

n. of particles upstream the filter	n. of particles downstream the filter	Beta ratio $\beta_x(c)$	Efficiency %
1.000.000	500.000	2	50
	100.000	10	90
	50.000	20	95
	13.000	75	98,7
	5.000	200	99,5
	1.000	1.000	99,9

3.1 Standards for Beta ratio determination

Since 1999 the **ISO16889** has been introduced as international standard to regulate the execution of Multi-Pass Tests to assess the Beta value of a filter element, replacing old ISO 4578.

ISO16889 considers the filter efficiency = 99,9% (β ratio > 1000), while for old ISO4572 the efficiency was lower = 99,5% (β ratio > 200), To avoid misunderstandings, particles measured to ISO16889 are identified as $\mu\text{m}_{(c)}$

The table below reports the Beta values of Atos filter elements, according to the considered standard.

Microfibre filter element	$\beta_{x(c)} > 1000$ (ISO16889)	$\beta_x > 200$ (ISO4572)
F03	4.5 $\mu\text{m}_{(c)}$	3 μm
F06	7 $\mu\text{m}_{(c)}$	6 μm
F10	12 $\mu\text{m}_{(c)}$	10 μm
F20	22 $\mu\text{m}_{(c)}$	20 μm
F25	27 $\mu\text{m}_{(c)}$	25 μm

Cellulose filter element	$\beta_{x(c)} > 2$ (ISO16889)	$\beta_x > 2$ (ISO4572)
C10	10 $\mu\text{m}_{(c)}$	10 μm
C25	25 $\mu\text{m}_{(c)}$	25 μm

Contamination classes and pressure drop values remain unchanged between ISO4572 and ISO16889

4 DIRT-HOLDING CAPACITY

The Beta ratio does not give any indication about the total amount of contaminant that can be trapped by the filter during its life.

This parameter is defined **DIRT-HOLDING CAPACITY (DHC)** and it defines the quantity of contaminant that the filter element can trap and hold before the maximum allowable back pressure or delta P level is reached.

Generally, a filter element with a larger effective filtration surface has a greater dirty holding capacity and therefore a longer service life.

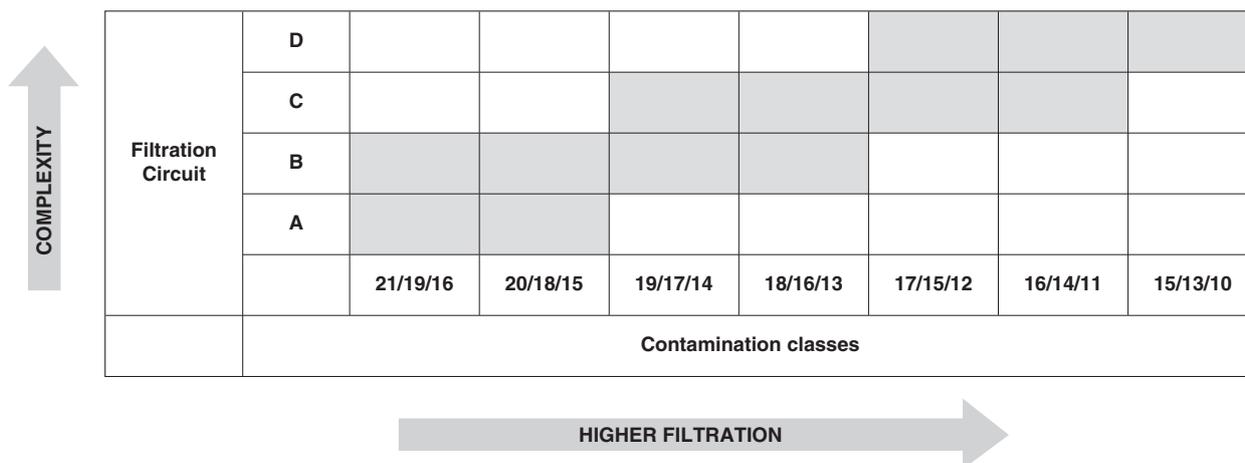
5 FILTRATION CIRCUIT

The solid contamination caused by normal component’s wear is the main source of fluid contamination.

To avoid malfunctioning and progressive deterioration of the components installed in the hydraulic system, a proper filtration circuit has to be designed.

The following recommendations support the user in designing of an optimized filtration circuit.

The table below suggests the selection of a filtration circuit according to the targeted contamination class, see section 1 for recommended contamination classes.



General rules to be followed to ensure optimal operating conditions for the hydraulic systems:

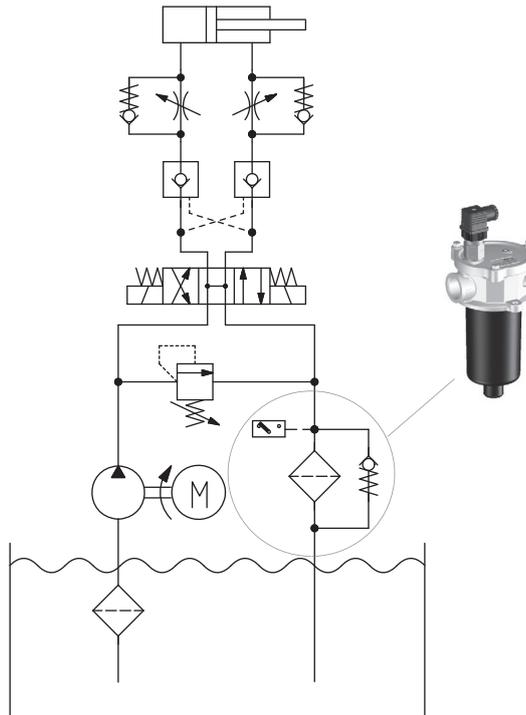
- the hydraulic tank has to be properly designed to limit the ingress of external contamination
- maintenance operations must be performed to avoid the ingress of contamination.

Consult Atos technical office for additional support for proper design of filtration circuits.

CIRCUIT A

Return line filter ensures that all the contaminants generated during system operations are correctly filtered before entering the tank. It is a cost effective solution mainly used in systems with on-off valves.

This configuration can't ensure protection of hydraulic components from wear generated by the pump.

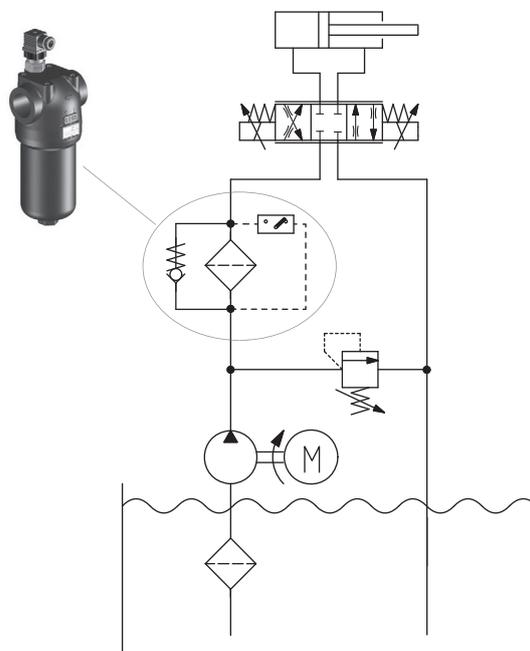


CIRCUIT B

In line filter is normally installed immediately after the pump, to guarantee a correct filtration of the fluid before it reaches the hydraulic components.

It is a solution particularly used to protect proportional and servoproportional valves.

This configuration can't ensure protection of hydraulic components from contaminants generated further downstream and of the pump from dirt returned to the tank.



CIRCUIT C

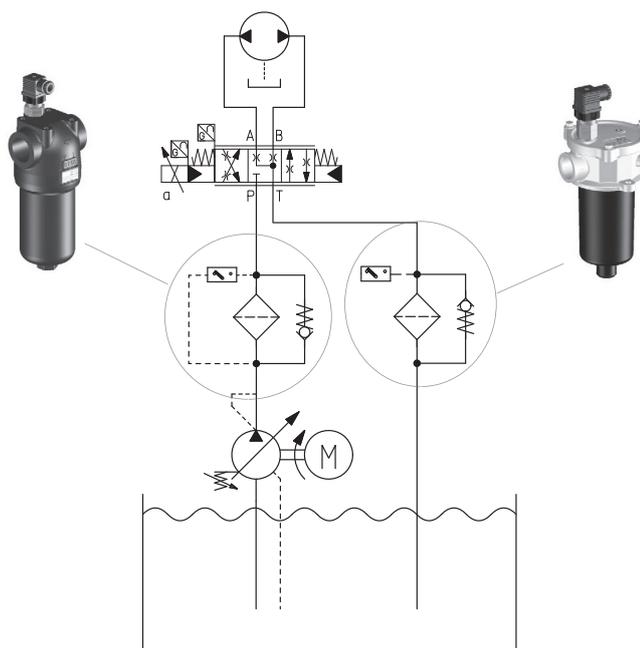
This example shows a circuit with **both in line and return line filters**.
It is an ideal solution to enhance the whole system efficiency.

This system configuration will ensure:

- correct protection of components from wear generated by the pump
- correct filtration of the fluid flowing back to the tank, removing all the contamination entered in the system as consequence of components wear.

An efficient contamination control is guaranteed if the whole pump flow is passing through the filters.

As consequence, this system configuration is not indicated for circuits with variable displacement pumps operating for long time in null flow.



CIRCUIT D

This example is similar to circuit C but implemented with an **additional off-line filtration system**.

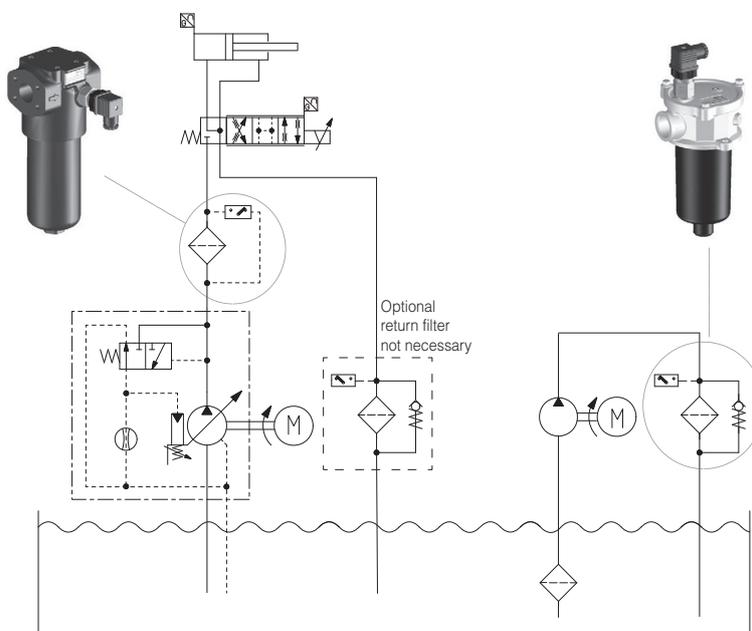
It is an ideal solution when wide change in system flow rates are expected or for systems equipped with variable displacement pumps operating for long time in null flow.

The additional off-line filtration system allows to maintain a constant filtration of the fluid in the tank, avoiding the accumulation of contamination particles

This system configuration will ensure:

- excellent cleanliness level, independently of the operating cycles of the main circuit
- higher dirt-holding capacity along with higher filtration efficiency
- easier maintenance operations thanks to the possibility of replacing the filter element without stopping the machine.

To protect critical components like servoproportional valves, in line filter without by-pass valves is suggested.



6 CLOGGING INDICATORS

They notify to the operator when the filter element is near to be clogged and then it must be replaced.

Their use is recommended for in line and return line filters to avoid that the high pressure caused by the clogged filter element causes the filter by-pass opening and the consequent release of contaminants into the hydraulic circuit.

Depending on the type of hydraulic filter, different clogging indicators are used:

- Visual indicator, Atos type **CIA-V**, normally used with **return line filters**

It is a pressure gauge which measures the pressure before the filter element and indicates the clogged condition by means of coloured sectors:

Green (range 0 to 3 bar) = filter element in good condition;

Red (> 3) = filter element to be immediately replaced

It requires a constant visual inspection by the operator to verify the filter condition



CIA-V

- Electrical indicator, Atos type **CIA-E**, normally used with **return line filters**

It is a pressure switch which measures the pressure before the filter element and it indicates the clogged condition by means of switching contact (NO or NC)

The switching pressure is factory set at 2 bar corresponding to 70% of the by-pass valve cracking pressure

The electric contact is normally interfaced with the machine CNC for the automatic monitoring of the filter condition



CIA-E

- Visual differential indicator, Atos type **CID-V**, normally used with **in line filters**

It is a pressure switch which measures the Δp across the filter element and it indicates the clogged condition by means of coloured bands:

Green = filter element in good condition;

Red = filter element to be immediately replaced

The switching pressure is factory set at 5 bar corresponding to 80% of the by-pass valve cracking pressure

For filters without by-pass valve the switching pressure is factory set at 8 bar

It requires a constant visual inspection by the operator to verify the filter condition



CID-V

- Electrical differential indicator, Atos type **CID-M**, normally used with **in line filters**

It is a pressure switch which measures the Δp across the filter element and it indicates the clogged condition by means of switching contact (NO or NC)

The switching pressure is factory set at 5 bar corresponding to 80% of the by-pass valve cracking pressure

For filters without by-pass valve the switching pressure is factory set at 8 bar

The electric contact is normally interfaced with the machine CNC for the automatic monitoring of the filter condition

Optional version, Atos code **CID-L**, is provided with additional LED to indicate the filter clogged condition



CID-E

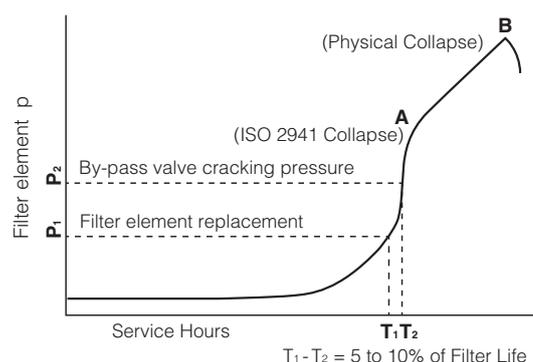
Notes about Electrical differential indicator function

The electrical differential clogging indicator switches at pressure P1, signalling the necessity to replace the filter element, before the by-pass valve cracking pressure P2.

To protect the system from contamination, the set value P1 of the clogging indicator is always lower than the cracking pressure P2 of the by-pass valve.

For in line filters without by-pass valve, the continued operation at higher Δp can cause the degradation of the filtration performances (point A in the diagram). In the worst case the filter element may collapse, losing its integrity (point B in the below diagram).

For this reason, in line filters without by-pass valves are usually provided with filter element having high collapse pressure value.



7 ISO STANDARDS

The following lists is intended to provide a documentation of the actual ISO norms relevant to hydraulic filtration

ISO 2941 Hydraulic fluid power – Filter element – verification of collapse/burst pressure rating

ISO 2942 Hydraulic fluid power – Filter element – verification of fabrication integrity and determination of the first bubble point

ISO 2943 Hydraulic fluid power – Filter element – verification of material compatibility with fluids

ISO 3723 Hydraulic fluid power – Filter element – method for end load test

ISO 3724 Hydraulic fluid power – Filter element – determination of resistance to flow fatigue using particulate contaminant

ISO 3968 Hydraulic fluid power – Filters – evaluation of differential pressure versus flow characteristics

ISO 4406 Hydraulic fluid power – Fluids – method for coding the level of contamination by solid

ISO 16889 Hydraulic fluid power – Filters – multi-pass method for evaluating filtration performance of a filter element

ISO 23181 Hydraulic fluid power – Filter element – determination of resistance to flow fatigue using high viscosity fluid

ISO 11170 Hydraulic fluid power – sequence of tests for verifying performance characteristics of filter elements

ISO 10771-1 Hydraulic fluid power – fatigue pressure testing of metal pressure-containing envelopes – test method