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Hydraulic fluid power — Monitoring the level of particulate contamination of the fluid —

Part 1:
General principles

Transmissions hydrauliques — Surveillance du niveau de pollution particulaire des fluides —

Partie 1: Principes généraux

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21018-1 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control*.

ISO 21018 consists of the following parts, under the general title *Hydraulic fluid power — Monitoring the level of particulate contamination of the fluid*:

- *Part 1: General principles*
- *Part 3: Use of the filter blockage technique*

A Part 2, dealing with the calibration and verification procedure for field contamination monitoring, and a Part 4, dealing with the use of the light extinction technique, are under development.

Introduction

In hydraulic fluid power systems, power is transmitted through a liquid under pressure within a closed circuit. The liquid is both a lubricant and power-transmitting medium. The presence of solid particulate contamination in the liquid interferes with the ability of the hydraulic liquid to lubricate and causes wear to the components. The extent of this form of contamination in the liquid has a direct bearing on the performance and reliability of the system and it is necessary that this be controlled to levels that are considered appropriate for the system concerned. Hydraulic filters are used to control the amount of particulate contamination to a level that is suitable for both the contaminant sensitivity of the system and the level of reliability required by the user.

Operators of hydraulic equipment are gradually defining maximum particle concentration levels for components, systems and processes, beyond which corrective actions are implemented to normalize the levels. These are often referred to as the required cleanliness level (RCL). The cleanliness level is obtained by sampling the hydraulic liquid and measuring the particulate contamination level. If the level is above the RCL, then corrective actions are necessary to restore the situation. To avoid taking unnecessary actions, which can often prove costly, precision in sampling and measuring the particulate contamination level is required.

A comprehensive range of measurement equipment is available, but the instruments used are usually laboratory-based. This often requires that the equipment is operated in a special environment by specialist laboratories and this delays delivery of the test result to the user. To overcome this disadvantage, instruments are being continuously developed to determine the particulate contamination level, either using equipment that can be operated in or near the workplace or directly using on-line or in-line techniques. For equipment operated in the workplace, direct traceability to national measurement standards might not be appropriate, or relevant, and the instruments are used to monitor the general level of particulate contamination or to inform the user of a significant change in the level. When a significant change in the particulate contamination level is detected, the actual level is then usually qualified by using an approved particle-counting method. Also, these monitors can have simplified circuitry compared to similar laboratory units and this means that they are not so precise.

In addition, some instruments are designed to work on the “go/no-go” principle and their ability to rapidly evaluate the cleanliness level has resulted in an increase in their usage both in the fluid power industry and other markets. Unfortunately, the lack of a standardized method for their use, recalibration (if applicable) and means of checking the output validity means that the variability in the measurement data is at a level higher than is desirable.

This International Standard has been developed to provide uniform and consistent procedures for instruments that are used for monitoring the contamination levels in hydraulic systems, especially those where direct traceability to national measurement standards is not possible or is not applicable.

Hydraulic fluid power — Monitoring the level of particulate contamination of the fluid —

Part 1:
General principles

1 Scope

This part of ISO 21018 specifies methods and techniques that are applicable to the monitoring of particulate contamination levels in hydraulic systems. It also describes the relative merits of various techniques so that the correct monitor for a given application can be selected.

The techniques described in this part of ISO 21018 are suitable for monitoring

a) the general cleanliness level in hydraulic systems,

b) the progress in flushing operations,

c) support equipment and test rigs.

This part of ISO 21018 can also be applicable for other liquids (e.g. lubricants, fuels and process liquids).

NOTE Instruments used to monitor particulate contamination are not considered as or claimed to be particle counters, even if they use the same physical principles as particle counters.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3722, *Hydraulic fluid power — Fluid sample containers — Qualifying and controlling cleaning methods*

ISO 4021, *Hydraulic fluid power — Particulate contamination analysis — Extraction of fluid samples from lines of an operating system*

ISO 4406:1999, *Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles*

ISO 5598, *Fluid power systems and components — Vocabulary*

ISO 11171, *Hydraulic fluid power — Calibration of automatic particle counters for liquids*

ISO 11500:1997, *Hydraulic fluid power — Determination of particulate contamination by automatic counting using the light extinction principle*

ISO 11943, *Hydraulic fluid power — On-line automatic particle-counting systems for liquids — Methods of calibration and validation*

ISO 12103-1:1997, *Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply.

3.1
automatic particle counter
APC
instrument that automatically counts and sizes individual particles suspended in a liquid using the light extinction principle

3.2
coincidence
detection of two or more particles as a single particle

NOTE Adapted from ISO 11500:1997, definition 3.2.

3.3
dynamic range
ratio of the largest and smallest particle size that a sensor can analyse

3.4
filter medium
fabric of the filter that removes and retains particles

3.5
gel
shapeless material that lacks definition and can interfere with the counting or monitoring process

NOTE Gels are usually formed by chemical reaction with the hydraulic liquid.

3.6
in-line analysis
analysis of a fluid sample of the liquid by an instrument that is permanently connected to a working flow line and where all of the liquid in that line passes through the sensor

3.7
off-line analysis
analysis of a fluid sample by an instrument that is not directly connected to the hydraulic system

3.8
on-line analysis
analysis performed on a fluid supplied directly to the instrument by a continuous line from the hydraulic system

NOTE The instrument can be either permanently connected to the flow line or connected prior to analysis.

3.9
mesh
type of filter medium that is made by weaving strands of wire or material filaments

3.10
particle size
characteristic dimension of a particle that defines the magnitude of the particle in terms of a physically measurable dimension related to the analysis technique used, such as the longest dimension or the equivalent spherical diameter and shall be stated in each standard

3.11
pore size
size of hole in the filter medium as stated by the instrument manufacturer

3.12
qualitative data
data that have less precision or accuracy than quantitative methods and usually gives results in ranges rather than exact numbers

3.13
quantitative data
data in the form of an exact numerical value of a parameter

3.14
required cleanliness level
RCL
liquid cleanliness level specified for a system or process

3.15
sampler
device for extracting a representative sample from a larger source

3.16
silt
very small particles (< 3 µm in size) that are present in the liquid, often below the minimum detection size of the technique used

NOTE 1 These can interfere with the effectiveness of the instrument either by obscuring particles or by coincidence effects.

NOTE 2 They can be small wear particles or products of hydraulic liquid degradation.

3.17
suction (sip) analysis
analysis of a sample drawn by instrument pump from a non-pressurized container and delivered to the instrument sensor

3.18
ISO codes
code defining the quantity and distribution of solid particles in the fluid used in a given hydraulic fluid power system, consisting of three numbers separated by a slash

EXAMPLE A code of 22/18/13 signifies that there are more than 20 000 and up to and including 40 000 particles equal to or larger than 4 µm(c), more than 1 300 and up to and including 2 500 particles equal to or larger than 6 µm(c) and more than 40 and up to and including 80 particles equal to or larger than 14 µm(c) in 1 ml of a given fluid sample.

See ISO 4406.

4 Health and safety

4.1 General

Operate the instrument in accordance with the manufacturer’s instructions and follow local health and safety procedures at all times. Personal protective equipment shall be used when required.

4.2 Electric power

Take care when connecting the instrument to an electrical power source and follow the manufacturer's instructions. Ensure that the correct safety fuse is fitted to electrical equipment.

4.3 Mechanical fluid power

Instruments shall be connected to pressurized lines in accordance with the instrument manufacturer's instructions and in such a manner that the connection is secure and leak free. Any connectors used shall be suitable for the pressure at the point of sampling.

Ensure that internal pressure has been dissipated before taking off any fittings or closures.

NOTE See Clause 6 for guidance regarding sampling from pressurized lines.

4.4 Process liquids

4.4.1 Volatile liquids

Flammable liquids shall be used

a) in accordance with the relevant material safety data sheet (MSDS),

b) at a temperature below the stated flash point,

c) away from potential sources of ignition.

The transfer of volatile liquids from one container to another container shall be carried out carefully due to the risk of sparking.

4.4.2 Solvents

Solvents shall be used in well-ventilated areas and the generation of an aerosol mist shall be avoided.

4.4.3 Electrical earthing/grounding

Apparatus used for filtering or dispensing solvents or any volatile flammable liquid shall be electrically earthed so as to avoid the risk of static discharge near the jet.

4.4.4 Environmental

All liquids and substances shall be disposed of in accordance with local environmental procedures.

Spillage shall be cleaned-up as detailed in the relevant MSDS.

4.4.5 Chemical compatibility

Ensure that all chemicals and fluids used in the various processes are chemically compatible with each other and with any equipment used.

5 Selection of monitoring technique

5.1 General

The eventual choice of which instrument or technique is chosen depends upon, but is not limited to, the following aspects:

a) how the instrument is to be used, i.e. the mode of operation;

b) purpose for which the analysis is required;

c) parameter(s) to be measured;

d) properties of the liquid.

5.2 Selection

Select the monitor by considering the operational parameters detailed in Annexes A and B and choose the instrument or technique that satisfies the individual requirements for monitoring.

NOTE Clause A.1 explains the modes of operation and analysis and Clause A.2 gives guidance on the various aspects to consider during selection and includes a selection matrix. Annex B gives a brief explanation of the different techniques and their advantages and disadvantages.

6 Procedures and precautions

6.1 General

Whichever monitoring or measurement technique is selected, there are a number of precautions that shall be taken to ensure that valid data are produced and errors are minimized.

This part of ISO 21018 gives general procedures that limit errors. Precautions relating to a specific technique are given in the relevant part of ISO 21018.

6.2 Obtaining representative samples

6.2.1 Select the sampling position consistent with the reasons for sampling. See ISO 4021.

NOTE 1 The importance of using the correct sampling technique(s) cannot be over-emphasized. The use of equipment connected to or mounted in or on the active flow line reduces the errors associated with extraneous contamination.

NOTE 2 The particulate contamination added to the sample from the sampling process can be much higher than the particulate concentration that exists in the liquid of some filtered systems.

The guidelines described in 6.3 to 6.6 are typical good practice for obtaining reliable results and should be read in conjunction with ISO 4021.

6.2.2 Use sampling valves that conform to ISO 4021.

6.2.3 For general monitoring, take the sample when the system is running and conditions are stable.

NOTE A period of 30 min after start-up is suitable.

6.2.4 For periodic monitoring of a machine or process, take repeat samples from the same place, in the same manner, when the machine or process is running normally and when operating conditions have stabilized.

6.3 Off-line sampling

6.3.1 Use sample bottles that have been cleaned and verified in accordance with ISO 3722.

6.3.2 Site the sampling valve consistent with the reason for sampling.

6.3.3 Position the sampling valve in a location where good mixing conditions exist.

6.3.4 Flush the sampling valve and transfer line at a flow rate of at least 2 l/min with a minimum flushing volume of 500 ml. Use higher flushing volumes (1 l to 3 l) if

a) valves do not conform to the requirements of ISO 4021,

b) long transfer lines are used,

c) the system liquid is clean (i.e. $\leqslant$ 14/12/9 in accordance with ISO 4406:1999).

6.3.5 Take the sample in a manner so as to minimize the ingress of environmental contamination.

6.3.6 Cap the sample immediately after it is taken and label with a unique identification.

6.3.7 Do not take samples from drain valves.

6.4 On-line analysis

6.4.1 Use sampling valves and procedures defined in ISO 4021.

6.4.2 Provide sufficient supply pressure to avoid instrument starvation or cavitation.

6.4.3 Flush the sampling lines with at least 1 l to 2 l of liquid sample after connection and before analysis.

6.4.4 Continue the analysis until the data from two successive samples satisfy one of the following requirements.

a) The results are within the limits set by the instrument manufacturer.

b) The difference in test results is less than 10 % at the minimum particle size being monitored if the required output is particle count.

c) The same cleanliness code is recorded.

6.5 In-line analysis

Install the instrument in a location

a) that is exposed to the majority of the flow;

b) where good mixing conditions exist.

6.6 Suction (sip) analysis from reservoirs or containers

6.6.1 Take the sample from a location where the liquid is in motion.

6.6.2 Shake and well mix the contents of static containers before extracting the sample.

NOTE This method is the least-favoured option as the potential for errors and variability is greatest.

If mixing the contents of a bulk container is impractical, a note shall be made in the report.

6.6.3 Clean the area(s) surrounding the location where the sample is taken so that contamination does not fall into the sample, the container or reservoir.

6.6.4 Flush the sampling system with at least 10 complete volumes (instrument and connecting pipes) of system liquid.

6.6.5 Continue the analysis until the data from successive samples satisfy one of the following requirements:

a) The results are within the limits set by the instrument manufacturer.

b) The difference in test results is less than 10 % at the minimum particle size being monitored if the required output is particle count.

c) The same cleanliness code is recorded.

6.7 Calibration procedures

Although the principle of calibration might not apply to some techniques, the requirements and principles of International Standards shall be followed wherever possible. For instance, where the instruments are automatic they shall be calibrated or checked using the A3 test dust (see ISO 12103-1;1997, Clause 3). In this way, any differences in the data measured using automatic particle counters (APC) calibrated using either ISO 11171 or ISO 11943 and data from those monitors calibrated/checked with suspensions of ISO 12013-A3 in oil are minimized.

Microscope-based techniques shall use the longest dimension as the measurement parameter.

6.8 Checking data validity

6.8.1 Develop a means of checking the data to ensure the prompt detection of errors before reporting the data. Use the procedures detailed below, as appropriate.

6.8.2 For automatic instruments, repeat the analysis until two successive data sets satisfy the following conditions.

a) The results are within the limits set by the instrument manufacturer.

b) The difference in test results is less than 10 % at the minimum particle size being monitored if the required output is particle count.

c) The same cleanliness code has been recorded.

6.8.3 Review the test data and confirm that they are of the same order as

a) previous data obtained from the same system or process,

b) previous data obtained from a similar system(s) using the same filtration level.

6.8.4 For off-line instruments where the sample is collected in a sample bottle, examine the sample for conditions that can interfere with the effectiveness of the instrument. Examples are given in a) to d) following:

a) The presence of large particles that can block small passageways, orifices or the sensor in the instrument. The presence of large particles can also indicate the presence of high numbers of smaller particles.

b) Test-liquid cloudiness, which can indicate the presence of another liquid such as water in oil, oil in water-based liquids, mixtures of liquids, etc., and which can interfere with instruments using the transmission of light to detect particles.

c) A clear but dark appearance in a test liquid often indicates the presence of finely divided particles (e.g. wear debris or oxidation products). The presence of finely divided particles in the test liquid can interfere with the effectiveness of the test instrument due to coincidence effects.

d) The presence of air bubbles in the test liquid interferes with the passage of light. Remove air bubbles before any analysis is performed.

6.9 Training

Train operators both in the technique and in the specific instrument used. Operator training shall be competence-based (where applicable).

NOTE The importance of proper and comprehensive training in both instrument use and the technique employed cannot be overstated as it is only with knowledge and experience that errors can be recognized and minimized.

Develop a training program that includes, but is not limited to

a) an explanation of the principles of the technique to be used, giving the advantages and disadvantages,

b) an explanation of the main features of the instrument,

c) training in the use of the instrument especially when dealing with samples that can give rise to difficulties,

d) basic problem solving.

It is recommended that users maintain operator training records.

6.10 Controlling the precision of the technique

6.10.1 Develop procedures to evaluate the competence of operators involved with using a technique where the results obtained are dependant upon operator competence.

6.10.2 Keep records to evaluate the level of reproducibility of the technique and whether operators are consistent. Retrain operators if there is a significant departure from the normal level of variability.

7 Test report

Report the results obtained from sample analysis and include the following as a minimum:

a) sample designation;

b) date of analysis;

c) instrument designation;

d) mode of analysis used;

e) analysis results and, if applicable, any action required;

f) any comments relating to the sample or results.

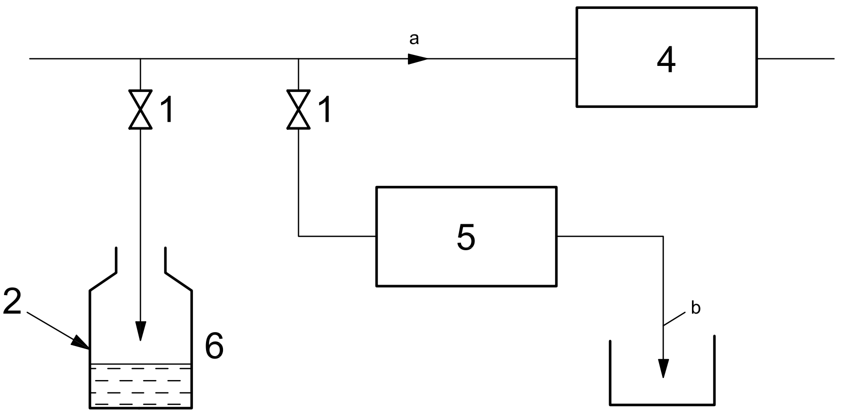
Annex A
(informative)

Summary of various technique attributes

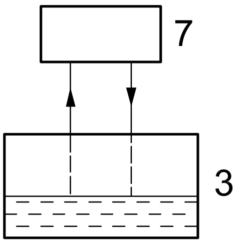
A.1 Modes of sampling and analysis

A.1.1 General

There are four methods (key items 4, 5, 6 and 7) of sampling and analysing liquid samples as shown diagrammatically in Figure A.1 and described in A.1.2 to A.1.5.



a) In-line, on-line and off-line sampling/analysis



b) Suction (sip) analysis

Key

1 sampling valve
2 sample bottle
3 reservoir or container
4 in-line analysis
5 on-line analysis
6 off-line sampling
7 suction (sip) analysis
a Flow direction.
b To reservoir or waste.

Figure A.1 — Operational mode diagram

A.1.2 Off-line analytical method

Off-line sampling and analysis is the most frequently used method and a wide range of techniques are available for use.

Off-line analysis involves the extraction of a representative liquid sample from the system, its collection in either a sample bottle or suitable container and subsequent analysis. The sample can be analysed in-house or by an external laboratory.

As a result of these processes, errors and hence variability in data can be introduced into the measured results and it is necessary to adopt appropriate procedures to limit the introduction of extraneous contamination into the sample (see 6.2.1).

NOTE Contamination can be introduced into the sample from

a) the sampling process,

b) the ambient environment (including the pipe work),

c) the analysis process.

A.1.3 On-line analytical method

For on-line analysis, the measuring instrument is connected either directly to the pipe work that is exposed to the active flow or to a subsidiary flow line attached to it.

On-line analysis overcomes the problems associated with the introduction of environmental contamination into the sample. However, contamination can be introduced into the sample as a result of connecting the measuring instrument to the system and then making the analysis before any residual contamination in the connecting line has been flushed out (see 6.4.3).

Most on-line instruments use a low flow rate (20 ml/min to 100 ml/min), which can be insufficient to flush the lines after connection, and pre-flushing of the connecting lines can be required. The flow rate used might not be able to generate sufficient disturbance at the sampling point to ensure that a representative sample is taken. In addition, small analytical volumes (e.g. 10 ml or 20 ml) can be inadequate for determining the true cleanliness level where particle numbers are low (see ISO 4406:1999, 3.4.6).

A.1.4 In-line analytical method

Instruments working in-line are permanently connected to the pipe work that is exposed to the active flow and provide a continuous measurement of cleanliness level. The errors associated with sampling described in A.1.2 are not experienced. This method requires good mixing conditions upstream of the measurement point so that the number of particles in the sensing volume is representative of those in the active pipe.

A.1.5 Suction (sip) analysis

For suction analysis, the measuring instrument is used to analyse the liquid from a non-pressurized container, for example a barrel of oil or a system reservoir (see Figure A.1). The requirement to transfer the liquid sample from the container to the sensor (e.g. by using an internal pump) can be a source of error. If it is necessary for the pump to lift the liquid to the instrument, a negative pressure (vacuum) is generated and this can draw air out of solution or through fittings. The presence of air in the liquid being analysed can interfere with the operation of the instrument and create errors. Additional errors can be introduced if the pump is positioned upstream of the sensor, where it can generate particles during operation and hence give unrepresentative test data.

Other sources of error are described in ISO 4021.

A.2 Selection of the most appropriate monitor

A.2.1 General

The eventual choice of which instrument or technique is chosen depends on, but is not limited to

a) the purpose for which the analysis is required (A.2.2),

b) the parameter(s) being measured (A.2.3),

c) how it is being used, i.e. the mode of operation (A.2.4),

d) the properties of the liquid (A.2.5).

This clause gives details of the parameters that it is necessary to consider before selecting the most suitable method to use. A summary of the attributes, in matrix form, is shown in Table A.7 and the various techniques are briefly described in Annex B. The categories identified might not fully describe the application under consideration and it is necessary to verify the suitability of the choice with the instrument manufacturer.

A.2.2 Reason for measuring or monitoring

The intended use of the measurement data and the desired accuracy govern the method chosen and dictate the level of instrument precision required.

For the general evaluation of cleanliness level and trend plotting, the measurement data can be qualitative (3.12), (e.g. as in ISO codes) and the use of a monitor can be a more appropriate alternative.

Certification of system or product cleanliness normally requires quantitative data (3.13).

A.2.3 Particle physical parameters

A.2.3.1 General

The choice of physical parameter relates closely to the purpose of the analysis (e.g. if a contamination code is required, then a size feature has to be chosen).

The various techniques that can be used are shown in Tables A.1 to A.6 and are listed alphabetic order and not in order of either suitability or ranking. In addition, guidance is given as to whether the technique gives qualitative or quantitative data.

A.2.3.2 Particle size

Information on the size of particles is required to evaluate the likelihood of a particle causing interference with clearances and/or of passageways.

Table A.1 — Particle size analysis techniques

Parameter	Quantitative data	Qualitative data
Length	Direct measurement (e.g. rule, micrometer) Image analysis Optical microscope Automatic particle counter Scanning electron microscope	None
Area	Image analysis Automatic particle counter Scanning electron microscope	None
Volume	Electrical sensing zone	Laser diffraction

A.2.3.3 Particle quantity

Information on the quantity of contaminant is used to evaluate both the extent of contamination and the probability of particle-induced problems.

Table A.2 — Particle quantity analysis techniques

Parameter	Quantitative data	Qualitative data
Particle count at specific sizes (size distribution)	Electrical sensing zone Image analysis Optical microscope counting Scanning electron microscope counting Automatic particle counting	Laser diffraction Filter blockage
Concentration at specific sizes	—	Laser diffraction Filter blockage Comparative membrane filter
Overall concentration (e.g. an index of severity covering a wide range of sizes)	Gravimetric analysis	Magnetic detection Thin film abrasivity Turbidity

A.2.4 Mode of operation

How the monitor analyses the fluid sample in off-line, on-line, in-line or suction (sip) modes is shown in Tables A.3 to A.6. See also A.1.

Table A.3 — Off-line operation analysis techniques

Quantitative data	Qualitative data
Direct measurement Electrical sensing zone Image analysis Magnetic detection Automatic particle counting Optical microscope counting Scanning electron microscopic counting	Comparative membrane filter Laser diffraction Filter blockage techniques Magnetic detection Thin film abrasivity Turbidity

Table A.4 — On-line operation analysis techniques

Quantitative data	Qualitative data
Automatic particle counting Image analysis Magnetic detection	Laser diffraction Filter blockage techniques Thin film abrasivity Turbidity

Table A.5 — In-line operation analysis techniques

Quantitative data	Qualitative data
Automatic particle counting Magnetic detection	Laser diffraction

Table A.6 — Suction operation analysis techniques

Quantitative data	Qualitative data
Automatic particle counting Image analysis	Laser diffraction Filter blockage Thin film abrasivity

A.2.5 Liquid types

It is necessary to consider the type of liquid only when the particles are analysed in the liquid itself and the condition of the liquid can interfere with the operation of the chosen technique.

A.2.6 Sample liquid characteristics and optical properties

A.2.6.1 Single, clear phase

Liquids analysed with instruments using light principles shall be clear and homogeneous and shall be without the presence of optical interfaces.

A.2.6.2 Multi-phase liquid

Multi-phase liquids can be either intentional (e.g. emulsions) or unintentional (e.g. tramp oils, water in oil, air in oil) and contain an optical interface between the phases. Any interface present in the sample interferes with the transmission of light through the liquid and erroneous data can be produced by instruments using optical techniques.

A.2.6.3 Opaque liquid

Opaque liquids can totally or partially obstruct the transmission of light through them, which interferes with the operation of the instrument. Light-based instruments, therefore, are not useable in these circumstances as there is insufficient light transmitted through the sample for accurate detection to take place.

A.2.7 Electrical properties

It is necessary to consider the conductivity of the liquid only when using the electrical sensing zone technique.

Table A.7 — Summary of various technique attributes

Technique	Operational [a]				Size µm			Output [a]				Output precision	Skill level [b]	Sample suitable for other analysis	Reference
	IN	ON	OFF	SIP	min.	max.	Dynamic range	Size	Number	ISO codes	Other				
Automatic counting	Y	Y	Y	Y	1,0	3 000+	100	Y	Y	Y	N	Quantitative	B	N	B.7
Microscope counting	N	N	Y	N	2,0	3 000+	200	Y	Y	Y	Type	Quantitative	A	Y	B.8
Image analysis	N	Y	Y	Y	2,0	3 000+	200	Y	Y	Y	Shape	Quantitative	B	Y	B.8
Laser diffraction	Y	Y	Y	Y	0,2	2 000+	10 000	Y	Y	Y	Volume	Qualitative	B	N	B.2
Filter blockage	N	Y	Y	Y	6	14	3,5	Y	N	Y	N	Qualitative	C	N	B.4
SEM	N	N	Y	N	0,01	3 000+	5 000	Y	Y	Y	Type and shape	Quantitative	A	Y	B.9
Direct measurement	N	N	Y	N	100	3 000+	N/A	Y	N/A	N	N	Quantitative	B	Y	N/A
Electrical sensing zone	N	N	Y	N	0,5	1 500+	100	Y	Y	Y	Volume	Quantitative	B	N	B.3
Comparison membrane	N	N	Y	N	5,0	3 000+	N/A	N	N	Y	Type	Qualitative	B	Y	B.1
Gravimetric	N	N	Y	N	1,0	3 000+	N/A	N	N	N	Mass	Quantitative	A	Y	B.5
Magnetic detection (i)	N	N	Y	N	0,5	3 000+	N/A	N	N	N	Arbitrary index	Qualitative	C	Y	B.6.1a)
Magnetic detection (ii)	Y	Y	Y	N	50	3 000+	100+	Y	Y	N	Magnetic and particles	Quantitative	C	N	B.6.1b)
Magnetic detection (iii)	Y	Y	N	N	15	3 000+	100+	N	N	N	Magnetic and particles	Quantitative	C	Y	B.6.1c)
Thin film	Y	Y	Y	Y	5,0	3 000+	N/A	N	N	N	Abrasivity Index	Qualitative	C	Y	B.10

[a] Y, yes; N, no; N/A, not applicable; IN, in-line; ON, on-line; OFF, off-line; SIP, suction (sip).

[b] A, requires a high level of training; B, requires a moderate level of training and skill in use and interpretation; C, requires a competent operator and skill in interpretation.

Annex B
(informative)

Description and relative merits of different contaminant monitoring techniques

B.1 Comparative membrane filter techniques

B.1.1 Outline

The comparative membrane filter technique is based upon an optical comparison of particles deposited on the surface of the sample membrane filter used in the test with a series of previously prepared reference membrane filters (or photographs of them) that represent different cleanliness levels. The sample membrane filters are prepared either off-line or on-line using the same filter pore size and analysis volume as the reference membrane filters.

After preparing the test sample membrane filter or images, the operator looks at the general concentration of particles on it using an optical microscope set at the same magnification used for viewing the reference filter membranes. The particle concentration is then compared to a series of reference membrane filters showing differing cleanliness levels. The reference membrane filter that is equal to or dirtier than the sample membrane filter is selected as being the cleanliness level for that sample.

This technique is often called the "patch test," as the membrane filter is frequently referred to as a "patch".

B.1.2 Key features

The following key features have been identified.

a) It takes approximately 5 min to prepare and analyse a sample.

b) It is low cost and hence cost effective.

c) A moderate operator skill level is required.

d) Problems with sample liquid can be seen.

e) It can be used to identify particle types and hence can be used as a diagnostic tool.

f) It can be used as a go/no-go technique.

B.1.3 Limitations

The following key limitations have been identified.

a) It can be used only as an off-line technique.

b) The total test time is dependant on the filtering time.

c) It is of limited use in the field where clean liquid levels occur due to environmental influence.

d) Samples require careful preparation to limit variability.

e) It does not give particle count or size analysis.

f) Particles can be obscured by silt and gels.

g) The degree of agreement with the reference sample is dependant on the relative particle-size distributions.

B.2 Laser diffraction analysers

B.2.1 Outline

Laser diffraction analysers are a form of light-scattering particle analyser that can be applied to a wide range of particle sizes and concentrations. Laser-diffraction analysers operate by directing a beam of filtered, low-power laser light, expanded to produce a parallel beam, across a sensing passage. As particles pass through the parallel beam, the light is scattered or diffracted at different angles depending on the size of the particle(s). The diffracted beam is then brought into focus on a multi-element solid-state detector. The particle-size distribution can then be established, either by calculation based upon the measured light-beam diffraction or by calibration using a specific test dust.

B.2.2 Key features

The following key features have been identified.

a) It can be used off-line, on-line and in-line with a glass-walled measurement section.

b) It can analyze a wide particle size range (0,2 µm to 2 000 µm).

c) It can be used to analyse high particle concentrations, e.g. > 20/18/15 (see ISO 4406:1999).

d) Typical analysis time is 5 min.

B.2.3 Limitations

The following key limitations have been identified.

a) It requires a high concentration of particles for accurate detection ≈ 19/17/14 (see ISO 4406:1999).

b) The particle size distribution is based upon particle volume.

c) It is not generally used in the fluid power industry.

d) The test set-up can be bulky.

e) It cannot be used with multi-phase liquids.

B.3 Electrical sensing zone

B.3.1 Outline

An electrically conducting liquid is drawn through a small, electrically insulated orifice having electrodes positioned in the liquid on either side of the orifice. When no particles are present, the impedance between the electrodes remains constant. When a particle having a conductivity different from that of the liquid passes through the orifice, it generates an electrical pulse proportional to the volume of the particle.

This type of unit is not frequently used for monitoring oil-based systems as the analysis process involves a number of other stages, either separating the particles and re-suspending them in an electrolyte or preparing a series of chemicals to make the oil conducting. The technique can be used in systems with water-based liquids.

Also see ISO 13319.

B.3.2 Key features

The following key features have been identified.

a) It can accommodate a wide particle size range (0,5 μm to 1 500 μm) by using different analytical orifices.

b) It provides precise, volumetric measurements.

c) It gives the particle-size distribution.

d) It typically has an analysis time of 5 min if the sample is analysed directly.

B.3.3 Limitations

The following key limitations have been identified.

a) It can be used only for off-line analysis.

b) It requires the test liquid to be electrically conducting.

c) It is necessary that the electrical conductivity of the particulate contamination present in the test sample be different from that of the carrier liquid.

d) The sample time is extended (typically by 20 min to 40 min) when the sample liquid is non-conducting.

e) It is not widely used in the fluid power industry.

B.4 Filter blockage method

B.4.1 Outline

The principle of the filter-blockage method is the determination of the change in the characteristics of a filter mesh or screen having a known number of uniform openings (or pores) as the contaminated liquid passes through it. Particles greater in size than the pore are removed and the filter gradually blocks up. This causes either the differential pressure across the filter to increase (constant-flow principle) or a reduction in the flow rate through the filter (constant-differential-pressure principle).

The concentration of particles in the test liquid sample with a size greater than the filter pore size can then be estimated either by considering the number of blocked pores (degree of blockage) and the volume of liquid that passed through the filter or by calibration. The test result is converted into a cleanliness code (see ISO 4406).

As the pressure drop across the filter is proportional to the viscosity, it is necessary to correct the data from constant flow units for changes in viscosity during the analysis cycle. The degree of correction depends on the instrument. Density changes over the analysis cycle have only a marginal effect.

Also see ISO 21018-3.

B.4.2 Key features

The following key features have been identified.

a) Several analytical modes are available:

   1) on-line from high- and low-pressure lines;

   2) suction mode from reservoirs and containers;

   3) off-line via sample bottles.

b) It can operate using a wide range of liquids (e.g. mineral and synthetic oils, emulsions, solvents, fuels, wash solutions and water-based liquids).

c) It can operate using liquids with optical interfaces (e.g. water in oil, air in liquids and immiscible liquids) provided the condition of the liquid remains constant over the analytical cycle.

d) It can operate over a wide range of contamination levels with a single unit.

e) It has a typical analysis time of 3 min to 6 min depending on the type of instrument.

B.4.3 Limitations

The following key limitations have been identified.

a) It has a restricted size range (current models usually have either one or two filters).

b) Constant-differential-pressure instruments cannot measure low levels of particulate contamination (e.g. < ISO */13/11).

c) Constant-flow instruments have a longer analysis time (about 8 min) for measuring low levels of particulate contamination (e.g. < ISO */10/8).

d) It does not analyse and record single particles so it is limited to monitoring general particulate-contamination levels.

B.5 Gravimetric analysis

B.5.1 Outline

In gravimetric analysis, the particles in the sample are separated from the liquid by vacuum filtration and deposited on a pre-weighed membrane filter ($\leqslant$ 1,0 µm pore size). After de-oiling and drying, the membrane filter is re-weighed and the mass of particles computed for the sample.

Also see ISO 4405.

B.5.2 Key features

The following key features have been identified.

a) It allows the measurement of large amounts of contaminant.

b) The contaminated membrane filter can be used in other analytical techniques.

B.5.3 Limitations

The following key limitations have been identified.

a) The technique is subject to significant errors at low contamination levels.

b) It is not suitable for clean systems (< 17/15/12; see ISO 4406) unless large volumes of contaminated liquid are analysed.

c) It has a typical sample analysis time of 35 min.

d) It does not provide a measure of particle-size distribution.

e) It requires support equipment (e.g. ovens and balances).

B.6 Magnetic detection

B.6.1 Outline

Instruments using magnetic detection measure the changes in the radiated magnetic field when passing through a test liquid containing magnetic and paramagnetic particles. Magnetic instruments are available in a number of configurations.

a) For some instruments, the sample (either a liquid containing particles, a membrane filter containing separated particles or a substrate containing magnetically separated particles) is inserted into the detector and a measure of the amount of magnetic material in the sample is given. The amount of magnetic material present in the sample can either be presented as a non-dimensional index or be measured in mass fraction through calibration. These instruments can analyze a wide range of particle sizes and can detect sub-micron particles ($< 0{,}5$ μm).

b) For some instruments, the magnetic detector is positioned in a flow line (in-line or on-line) and detects the individual particles as they pass by. This type of instrument can detect only large particles (> 75 μm) and gives a measure of the number of particles based upon their volume.

c) For some instruments, the particulate material is collected by a magnet and the capacitance of the sensor changes as the concentration of collected particles increases. The debris can be removed either by switching off the magnet or by vaporizing it using a high voltage. These instruments are called “chip detectors”.

B.6.2 Key features

The following key features have been identified.

a) It performs a rapid analysis of the magnetic debris (typically 5 s for debris analysers).

b) It is simple to operate.

c) The instruments are often inexpensive.

B.6.3 Limitations

The following key limitations have been identified.

a) It is useful only when the particles are magnetic and paramagnetic.

b) The test data do not give particle size distribution or ISO codes.

c) It has a limited effectiveness when used with clean samples ($<$ 17/15/13; see ISO 4406) unless large volumes of contaminated liquid are analyzed.

d) The test result output is often in arbitrary units.

B.7 Automatic particle counting

B.7.1 Outline

In automatic particle-counting instruments, the sample being analysed is passed through a narrow passage, which is illuminated (e.g. by using a low power laser) in the instrument sensor. As a single particle passes through the light beam, the amount of light received by the detector (usually on the opposite side of the flow stream) is reduced in proportion to the projected surface area of the particle. The passage of the particle through the light beam thus produces a voltage pulse, which is analysed by the instrument and its presence is recorded. The size/voltage relationship for the instrument/sensor combination is obtained by calibration using either ISO 11171 or ISO 11943. The analytical cycle involves the passage of a selected volume of the sample through the sensor.

Also see ISO 11500 and ISO 21018-4.

B.7.2 Key features

The following key features have been identified.

a) It can be used for several analysis modes:

  - on-line from a high or low pressure supply,
  - in-line, permanently mounted to the system,
  - suction (sip) mode from reservoirs and bulk containers,
  - off-line via sample bottles;

b) It can accommodate a wide range of particle sizes from 1,0 µm to 3 000 µm (the dynamic range of these instruments is usually 50 to 100 depending on design).

c) It has a typical analysis time of between 2 min and 15 min depending on the analytical mode.

d) It functions automatically and so on-line units do not require an operator.

e) It can accommodate a wide range of particle concentrations without requiring dilution.

f) It can analyse very clean liquids with good accuracy, provided that higher volumes are analysed to improve particle-count statistics.

g) It is relatively simple to use but does require skill in data interpretation.

B.7.3 Limitations

The following key limitations have been identified.

a) It requires that the liquid be clear and homogeneous.

b) Erroneous particle counts result if liquid interfaces are present (e.g. water in oil, air in liquid, mixtures of immiscible liquids, emulsion liquids).

c) Heavily contaminated liquids require dilution prior to analysis otherwise the results can be erroneous.

d) Counting accuracy is affected by the presence of large numbers of small particles often below the instrument minimum-size setting.

e) Off-line analysis requires a “controlled” environment.

f) Large (> 200 µm) particles can block the sensor.

g) The analysis results can be affected by the condition of the liquid (e.g. gels and opacity).

B.8 Optical microscope particle counting

B.8.1 Outline

The particles contained in a sample of hydraulic liquid are separated from it by vacuum filtration and deposited on a membrane filter. The pore size of the membrane filter depends on the condition of the liquid and the minimum size being counted, but is usually 1,2 µm. The membrane filter is generally overprinted with a 3,1 mm square grid to assist manual counting. However, plain membrane filters are used for image analysis.

After drying, the membrane filter is either analysed directly using an optical microscope fitted with top or incident lighting or made transparent for analysis using transmitted light. The particles are then sized in terms of their longest dimension using a calibrated eyepiece graticule (manual counting) or in relation to the number of pixels the particle occupies (image analysis). Both methods are calibrated using a stage micrometer whose calibration is traceable.

For manual counting, statistical counting techniques are used to reduce process time. Individual particles on a selected number of grid squares are sized, counted and the counts obtained at any one size are then corrected for the total sample volume passed through the membrane filter. Automatic counting using image analysis allows the complete surface of the membrane filter to be analyzed. Different microscope lens magnifications are used to classify different particle sizes.

Also see ISO 4407.

B.8.2 Key features

The following key features have been identified.

a) It is considered a reference method and most ISO counting methods are referred to this technique.

b) It can cover a wide particle size range (2 µm and above).

c) Particles are visible, hence potential counting problems can be seen.

d) It has low equipment cost when manual counting is used.

e) Information on particle type is available, if required.

f) It is independent of liquid condition provided the liquid can be filtered.

g) It can be automated by using image analysis techniques to reduce operator error and enhance accuracy.

B.8.3 Limitations of manual counting

The following key limitations have been identified.

a) A high skill level is required.

b) A typical count at six sizes takes 30 min.

c) It requires a controlled environment.

d) Off-line analysis only.

e) Particles can be obscured by silts, gel, etc.

B.8.4 Limitations of image analysis counting

The following key limitations have been identified.

a) Image analysis can require manual editing to account for coincident (overlapping) or out-of-focus particles. This increases analysis time.

b) It requires analysis at other magnifications for more representative results.

B.9 Scanning electron microscopy (SEM)

B.9.1 Outline

A small section (usually 1 cm^2) of a membrane filter containing the particles is mounted on an aluminium stub and sputter-coated with a conducting layer (gold, silver or carbon). The specimen is placed in the SEM vacuum chamber and bombarded with electrons. The electrons illuminate the specimen (much in the way that photons do in light microscopy) and an image is displayed on a monitor. This image is processed electronically in a manner similar to that for image analysis (see Clause B.8) and can give a similar output.

When the electron beam is focussed onto the sample surface, it ionizes the atoms and generates X-rays characteristic of the material. From an analysis of the resulting spectrum, the elements making up the particle can be identified and quantified.

Also see ISO 16232-7 and ISO 16232-8.

B.9.2 Key features

The following key features have been identified.

a) It has a high resolution (particles down to 0,01 µm can be detected).

b) It can give particle size and number when image analysis is used.

c) It gives the elemental particle composition.

d) It gives a high-definition image with little depth-of-field limitations.

e) It can map particles based upon their type and size when used with suitable software.

B.9.3 Limitations

The following key limitations have been identified.

a) It is a laboratory technique only.

b) It has high purchase costs and is time consuming; a typical analytical time is 1 h to 3 h.

c) It requires a skilled operator.

d) There is limited penetration of the electrons into the material (≈ 5 µm).

B.10 Thin layer abrasivity monitor

B.10.1 Technique

The monitor is fitted to a subsidiary line of the hydraulic system (on-line) and a nozzle directs the flow at a relatively high velocity (25 m/s) onto one of two metal strips in the sensor. The second metal strip in the sensor is diametrically opposite the first. The sensor strips have a thin conducting film vacuum-coated on and are electrically connected to form a bridge network. Particles that come into contact with the forward facing (active) sensor remove some of the deposited film and change the resistance of the strip. The change in resistance is proportional to the concentration, hardness and abrasivity of the particles. The instrument records the change in resistance with time and frequency of occurrence and presents this as “abrasivity”. Large single particles can be detected.

B.10.2 Key features

The following key features have been identified.

a) It gives information on particle hardness and abrasiveness.

b) It is an on/in-line instrument.

B.10.3 Limitations

The following key limitations have been identified.

a) It does not give a measure of particle size, number or ISO code in accordance with ISO 4406.

b) It is not in frequent use in the fluid power industry.

c) The result is dependant on liquid viscosity.

d) The results can vary with particle hardness.

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1) Under development.

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