SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP5376 REV. A

Issued 1998-09
Revised 2003-01

Superseding ARP5376

Methods, Locations and Criteria for System Sampling and Measuring the Solid Particle Contamination of Hydraulic Fluids

INTRODUCTION

General:

The performance of modern hydraulic equipment for aerospace purposes is widely determined by the type and condition of the applicable hydraulic fluids.

The quality and serviceability of these hydraulic fluids are dependent on various factors (e.g., thermal stability, viscosity), in particular on the level of solid particle contamination, which requires regular control if it is to be kept within the given limits.

This recommended practice draws from aerospace industry experience and practice. It establishes recommended criteria for fluid contamination sampling and analysis of particulate contaminants in aerospace vehicle hydraulic systems. To obtain comparable test results, uniform test methods as given in this recommended practice should be used.

Effects of Solid Particle Contamination:

Solid particle contaminants have been linked to abrasive wear, contact fatigue, and fouling of critical passages, thereby shortening the life of the components in a hydraulic system.

Solid particle contamination may have the following effects within a hydraulic system:

a. components are subject to erosion (primarily in components with higher fluid velocities such as pressure control or servo valves);
b. all moving parts are subject to wear by abrasion;
c. control valves are subject to silting (settlement of fine particles around the metering edges);
d. critical passages may become blocked leading to functional failure.

SAENORM.COM : Click to view the full PDF of arp5376a

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be reaffirmed, revised, or cancelled. SAE invites your written comments and suggestions.

Copyright 2003 Society of Automotive Engineers, Inc.
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: custsvc@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

Sources of Solid Particle Contamination:

Solid particle contamination of hydraulic fluids may be system-generated, introduced from the outside, built-in during manufacturing or maintenance-generated, and may include but is not limited to:

a. dust particles in the air;
b. metal particles, produced during the manufacture of parts;
c. sand residues on castings;
d. abrasion of seals;
e. oxide layers on welding seams and on heat-formed or heat-treated steel parts;
f. chemical and physical changes in the condition of hydraulic fluids;
g. maintenance of hydraulic systems (e.g., fibers from rags, contamination from disassembly and assembly of fittings, dirty quick disconnects on fluid servicing carts, etc.);
h. wear of components;
i. ingress of particles via rod gland seals and wipers.

Outline of This Recommended Practice:

This recommended practice consists of four major parts:

a. cleaning of apparatus and sample bottles, where used (Sections 3 to 6);
b. sampling location, apparatus, collection methods, and frequency (Sections 7 to 10);
c. analysis methods for solid particle contamination (Sections 11 to 13);
d. data reporting (Section 14).

1. SCOPE AND FIELD OF APPLICATION:

This SAE Aerospace Recommended Practice (ARP) provides procedures for assuring cleanliness of sampling equipment, for performing the sampling process, and for measuring and reporting the sample particle count.

The ARP specifies procedures for cleaning sample bottles, when used, and recommends the solvents to be applied and how these solvents should be prepared.

Requirements for the selection of the sampling point, sampling method, and sampling frequency are also specified.

This ARP also specifies three measuring methods for determining the level of solid particle contamination of hydraulic fluids used in aerospace hydraulics. These are:

a. on-line automatic particle counting;
b. automatic particle counting method using bottle samples;
c. microscopic particle count method using bottle samples.

SAENORM.COM : Click to view the full PDF of arp5376a

2. APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP598	The Determination of Particulate Contamination of Liquids by the Particle Count Method
ARP4285	Evaluation of Particulate Contamination in Hydraulic Fluids – Membrane Procedure
AS4059	Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids

2.2 ISO Publications:

Available from International Organization for Standardization, 1 rue de Varembe, 1121 Geneva 20 Switzerland. (Also available from ANSI, 25 West 43rd Street, New York, NY 10036-8002 and NFPA, 3333 N. Mayfair Road, Milwaukee, WI 53222-2319.)

ISO 3722	Hydraulic fluid power - Fluid sample containers - Qualifying and controlling cleaning methods
ISO 4407	Hydraulic fluid power - Fluid contamination - Determination of particulate contamination by the counting method using a microscope
ISO 11171	Hydraulic fluid power - Calibration of automatic particle counters for liquids
ISO 11500	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

SAENORM.COM : Click to view the full PDF of arp5376a

3. GENERAL CLEANLINESS:

When establishing the level of solid particle contamination of hydraulic fluids, the test results may be adversely affected by not sufficiently taking account of the need for optimum cleanliness of the sampling and analysis equipment.

In order to obtain meaningful results reproducible at any place and at any time, it is essential to ensure that the preliminary conditions prevent any additional solid particle contamination of the hydraulic fluid sample taken.

Additional solid particle contamination can be caused by using apparatus inadequately cleaned for the measurement.

All apparatus used for sampling and determining the solid particle contamination level of hydraulic fluids should be thoroughly cleaned before use. The apparatus should be resistant to the solvent and the sample fluids.

4. USE OF SOLVENTS:

The following solvents are recommended for the cleaning procedure:

a. Solvent A: De-mineralized, distilled or de-ionized water, or water from conversion osmosis.
b. Solvent B: 2-propanol (isopropyl alcohol), reagent-pure.
c. Solvent C: Petroleum ether or other suitable equivalents.

WARNING: Use precautions and consult applicable safety regulations when using flammable solvents.

5. FILTRATION OF SOLVENTS:

5.1 Pressure Filtration:

Pressure filtration of solvents using an inert gas pressurized solvent tank is generally the most convenient method to dispense clean solvent.

5.1.1 Use the following typical apparatus:

a. pressure tank, stainless steel;
b. filter-jet spray gun, with filter attachment;
c. membrane filter, having an aperture size less than or equal to 0.5 µm.

5.1.2 Procedure: The filter-jet spray gun (5.1.1b), with a membrane filter (5.1.1c) fitted, should be connected by a hose to the pressure tank (5.1.1a) containing the solvent. The gun should produce a concentrated jet of filtered solvent for cleaning the surfaces. Precleaning is not required.

SAENORM.COM : Click to view the full PDF of arp5376a

5.2 Vacuum Filtration:

Vacuum filtration of solvents can be used as an alternative to pressure filtration, however, a final filter using a membrane filter (5.2.1d) is still required on the dispensing wash bottle to ensure clean solvent is being dispensed.

5.2.1 Use the following typical apparatus:

a. vacuum pump;
b. filtration apparatus, stainless steel or glass;
c. wash bottles;
d. membrane filter, having an aperture size less than or equal to 0.5 µm.

5.2.2 Procedure: For vacuum filtration of the solvent, the filtration apparatus (5.2.1b) should be fitted with a membrane filter (5.2.1d) and connected to the vacuum pump (5.2.1a) by a hose. The solvent should be filtered through the membrane filter by the vacuum in the flask of the filtration apparatus. The filtrate collected in the flask should be transferred to the corresponding wash bottle (5.2.1c). The wash bottle should only be used with a membrane filter (5.2.1d) fitted.

6. SAMPLE BOTTLES:

Sample bottles, when used, should preferably be made from glass, should have a nominal capacity of 250 mL and a minimum capacity of 150 mL, and should be sealed by means of caps (preferably of phenolic resin) which will not cause contamination. Otherwise a non-flaking plastic film compatible with the hydraulic fluid should be used. Bottles made of non-flaking polyethylene have also been used with success.

6.1 General Cleaning Requirements:

Before use, sample bottles and caps should be thoroughly cleaned in accordance with a qualified procedure such as the procedure described in 6.2. In carrying out steps d to f, care should be taken to ensure that the whole surface of the sample bottle is pressure-rinsed from top to bottom. Optionally, pre-cleaned sample bottles may be obtained from a qualified source adhering to the requirements below.

SAENORM.COM : Click to view the full PDF of arp5376a

6.2 Recommended Cleaning Procedure for Sample Bottles:

The following method has been qualified to produce acceptable bottle cleanliness:

a. rinse with a degreasing fluid;
b. wash thoroughly in a filtered hot water solution of detergent;
c. rinse twice with filtered hot water at a temperature of between 40 °C and 60 °C;
d. rinse twice with solvent A, filtered through a membrane filter having an aperture size less than or equal to 0.5 µm;
e. rinse three times with solvent B, filtered through a membrane filter having an aperture size less than or equal to 0.5 µm, to remove water;
f. rinse three times with solvent C, filtered through a membrane filter having an aperture size less than or equal to 0.5 µm.

After the last rinse, a small amount (<10 mL) of solvent C should remain in the sample bottle. The resultant gas pressure inside the sample bottle avoids contamination when the bottle is opened. When using a piece of plastic film, 100 mm x 100 mm, the film should be rinsed with filtered solvent C and then placed over the mouth of the sample bottle with the edges of the film bent downwards and the cap screwed onto the bottle. The cap should not be tightened too hard to avoid breaking the plastic film.

6.3 Checking and Controlling Cleaning Methods:

Check the cleaned sample bottles in accordance with ISO 3722. The required cleanliness level (RCL) for the bottles should be less than 1% of the expected cleanliness level of the system fluid to be sampled. If the expected cleanliness is unavailable, use an RCL corresponding to AS4059, Class 0.

7. LOCATION OF SAMPLING POINTS:

7.1 The hydraulic system designer should select the hydraulic system sampling point(s) at the time of design for fleet standardization consistent with system cleanliness requirements. Users may require optional sampling points to satisfy their unique maintenance requirements.

7.2 The sampling point(s) should be located in a readily accessible area and should allow convenient use of on-line analysis or sample bottles.

7.3 The following sampling points relative to system filters will provide fluid from various points in the system with different cleanliness levels.

7.3.1 Upstream of the main return filter provides indication of contamination coming from system components and is the most useful sample for diagnosing system condition.

SAENORM.COM : Click to view the full PDF of arp5376a

7.3.2 Upstream of the hydraulic pump case drain filter provides indication of contamination coming from the hydraulic pump. The pump case drain fluid can be the system's most heavily contaminated area due to pump generated wear particles.

7.3.3 Downstream of the main return filter and upstream of the hydraulic pump verifies return filter performance and provides indication of contamination going to the reservoir and pump: - The case drain line may also contribute considerable contamination to the reservoir depending on system configuration.

7.3.4 Downstream of the main pressure supply filter provides indication of contamination going to the actuation system. In the supply side of the hydraulic system, the contamination level is lowest at the outlet of the pressure filter and is increased by debris picked up on the way to the actuation system. Secondary filters are often installed immediately upstream of sensitive components to protect them from large particle debris.

7.3.5 Locations at the hydraulic reservoir and at filter bowls are not recommended for particulate contamination measurement, no matter how convenient. Samples from these points do not provide clear stream full flow conditions and are not considered representative of the hydraulic system fluid cleanliness.

7.3.6 The fluid is expected to be cleaner downstream of filters. The fluid cleanliness criteria should take this fact into account.

7.4 Recommendation:

Although a number of potential sampling point locations exist in a vehicle hydraulic system to obtain fluid samples for contamination measurement, the location upstream of the return line filter is considered to be the single most useful sampling point location for diagnosing system condition.

8. SAMPLING APPARATUS:

There are two methods acceptable for sampling from aircraft hydraulic systems. The first method, detailed in 8.2, is for on-line analysis where an automatic particle counter is connected directly to the line of an operating system. The second method, detailed in 8.3, is for extracting a bottle sample for subsequent analysis. The on-line method is preferred because of enhanced accuracy, immediate results, and no requirement for clean sample bottles.

Each hydraulic system in aerospace vehicles should have a permanent hydraulic fluid sampling point or points with convenient access, and located by the hydraulic system designer.

SAENORM.COM : Click to view the full PDF of arp5376a

8.1 Permanent Sampling Connection:

Extract sample fluid from main hydraulic fluid lines in a section where turbulent mixing conditions exist. A permanent sampling connection consisting of either a quick disconnect or valve should be attached to the hydraulic line. The sampling adapter should have the following characteristics:

a. be easy to use and leak free;
b. be compatible with the fluid and the maximum operating temperature at the sample point;
c. be compatible with the structural requirements of the aircraft application including such parameters as vibration resistance, fatigue and burst pressure ratings;
d. be compatible with the sampling procedure to be used;
e. give repeatable and reproducible samples;
f. be so constructed to minimize areas where particulate contamination may settle out when the adapter is not in use; to minimize generation of contaminants by the adapter itself; and to be of the type that cleans itself by flushing;
g. be qualified by laboratory tests to ensure that the contamination level sampled is representative of the system fluid. The contamination level at the outlet of the device should be within 5% of the contamination level at the inlet for the range of contamination levels expected in service.

In addition to these characteristics, the quick disconnect or sample valve should have the following characteristics:

8.1.1 Quick Disconnect Sample Adapter: Permanent quick disconnect adapters should:

a. include a positive shut off valve to prevent flow when not in use;
NOTE: For sampling, this valve is actuated by the matching adapter on the sampling device.
b. include a separate dust cap, which eliminates atmospheric contamination and also serves for positive secondary leak prevention when adapter is not in use.

8.1.2 Permanent Sampling Valve: When a sampling valve is permanently installed, it should:

a. be automatic closing;
b. include a separate dust cap which eliminates atmospheric contamination and also serves for positive secondary leak prevention when sample valve is not in use;
c. not be used to regulate flow during the sampling process.

8.2 On-line Sampling Apparatus:

For application of on-line sampling and particle counting, a hose should be connected between the permanent sampling connection and the automatic particle counter (see example, Figure 1).

8.2.1 Use an automatic particle counter, which is compatible with the system fluid, operating temperature and pressure.

SAENORM.COM : Click to view the full PDF of arp5376a

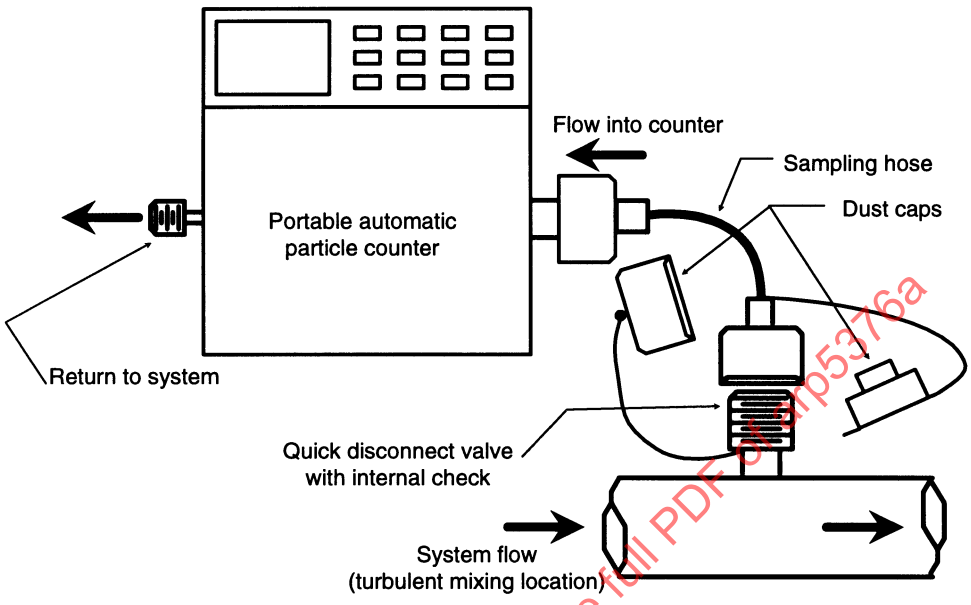

FIGURE 1 - Example Sampling Setup for On-line Automatic Particle Counting

8.2.2 Use a hydraulic hose and adapters, which are compatible with the system fluid, operating temperature and pressure. They shall be clean prior to use, capped when not in use, and it is best if they are dedicated for sampling use only.

8.2.3 The hose should have a small inside diameter, e.g., 1.5 to 3 mm.

8.2.4 Connect the outlet from the particle counter to any convenient point in the system downstream of the sampling point with a pressure level consistent with the ratings of the particle counter, e.g., downstream of the filter or into the system reservoir.

NOTE: The return fluid from the particle counter can be collected in an external vessel as long as the hydraulic system fluid volume requirements are not compromised.

8.3 Bottle Sample Apparatus:

When bottle samples are required, a small diameter tube on the outlet of the permanent sampling connection may be necessary to reduce sample flow rate. (see example in Figure 2). The tubing should have an inside diameter no smaller than 1 mm.

9. BOTTLE SAMPLING METHOD:

9.1 System Operation Prior to Sampling:

9.1.1 Sample within 1 h after landing the aircraft.

SAENORM.COM : Click to view the full PDF of arp5376a

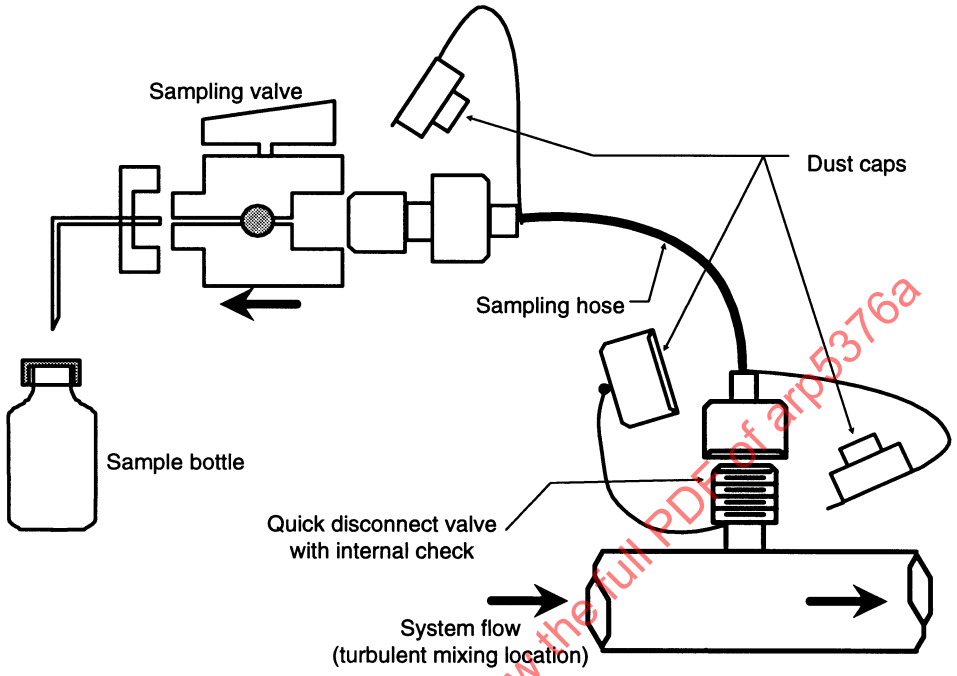

FIGURE 2 - Example Setup for Bottle

9.1.2 When sampling just after landing is not practical, the aircraft hydraulic systems should be operated at full flow, or the highest flow possible, while exercising the control surfaces to ensure that the fluid circulating is representative of the aircraft system at near flight conditions. If an extensive time has expired since landing, a longer circulation time should be allowed to adequately diffuse the contaminants throughout the system fluid.

NOTE: It is recommended that the system be operated for a minimum of 15 minutes at a fluid temperature of greater than 30 °C.

9.4 Bottle Sampling Procedure:

9.4.1 The sampling adapter on the hydraulic system should be capped. Wipe the dust cap clean with a clean and preferably lint-free cloth, then remove the cap.

9.4.2 Attach the sampling hose and valve if used.

9.4.3 Successively open and close the sampling valve three to four times for a short period.

9.4.4 Open the sampling valve and release into a waste container a volume of hydraulic fluid to flush the sampling system (a minimum volume of 100 mL is recommended) but not less than five times the total internal volume of the sampling apparatus.

SAENORM.COM : Click to view the full PDF of arp5376a

9.4.5 Remove the sealing cap, with plastic film, if used, from the sample bottle (6.2) and drain off solvent from the bottle. Fill the sample bottle between 50 to 80% of its capacity.

NOTE: Do not overfill bottle, as empty space is required for proper sample agitation.

9.4.6 Control the sample flow rate (100 to 500 mL/min recommended), if required, with a length of capillary tubing, not by adjusting the valve. Alternate sample valves that provide a controlled stream of flow without adjustment may be used. Such valves must be demonstrated to have no influence on the sampled contamination level.

9.4.7 Do not actuate the sampling valve throughout the sampling period.

9.4.8 Remove the bottle from sampling stream.

9.4.9 Close the sample bottle with sealing cap, and plastic film, if used.

9.4.10 Close the sampling valve and uncouple the quick disconnect if used. To avoid contamination, do not wipe the sampling valve.

9.4.11 Replace the dust cap on the sampling adapter.

9.4.12 Identify the sample with information as described in 13.3.

10. SAMPLING FREQUENCY:

10.1 The sampling frequency should be selected and monitored by the operator as required to meet the needs of contamination control. The time between samples should be based on operating experience in anticipation of reaching the specified allowable contamination level. The time between samples should be increased prudently with introduction of a new model aerospace vehicle. An Initial sampling frequency of 6 to 12 months or 1500 h, whichever comes first is recommended.

10.2 Sampling is recommended following failure and/or replacement of system components. System filters should be inspected and changed or cleaned as necessary following component failure.

10.3 Sampling is recommended following any abnormal events during flight, which might be related to particulate, e.g., low, high or fluctuating hydraulic pressure.

10.4 The prime manufacturer should sample the hydraulic fluid after initial flushing during manufacture and at the time of delivery.

SAENORM.COM : Click to view the full PDF of arp5376a

11. ANALYSIS METHOD USING AN ON-LINE AUTOMATIC PARTICLE COUNTER:

11.1 System Operation Prior to Sampling and Analysis:

11.1.1 Sample within 1 h after landing the aircraft.

11.1.2 When sampling just after landing is not practical, the aircraft hydraulic systems should be operated at full flow, or the highest flow possible, while exercising the control surfaces to ensure that the fluid circulating is representative of the aircraft system at near flight conditions. If an extensive time has expired since landing, a longer circulation time should be allowed to adequately diffuse the contaminants throughout the system fluid.

NOTE: It is recommended that the system be operated for a minimum of 15 min at a fluid temperature of greater than 30 °C.

11.2 On-line Sampling and Analysis Procedure:

The on-line particle counting procedure should be carried out with reference to the automatic particle counter manufacturer's instruction.

11.2.1 Calibrate and maintain the automatic particle counter in accordance with ISO 11943 and ISO 4402 prior to use.

11.2.2 The sampling adapter on the hydraulic system should be capped. Wipe the dust cap clean with a clean and preferably lint-free cloth, then remove the cap.

11.2.3 Attach the hose and automatic particle counter to the quick disconnect coupling or valve.

11.2.4 Open the sampling valve, if used.

11.2.5 Flush the hose, connectors and particle counter with a volume of fluid (a minimum of 100 mL is recommended) until the particle counts have been stabilized. Discard any particle counts obtained during this flush.

11.2.6 Obtain three consecutive particle counts for an average calculation.

11.2.7 Do not actuate the sampling valve, if used, throughout the sampling period.

11.2.8 Close the sampling valve, if used.

11.2.9 Disconnect the hose and particle counter.

11.2.10 Replace the dust cap.

SAENORM.COM : Click to view the full PDF of arp5376a