SAE International SURFACE VEHICLE STANDARD

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(R) Automatic Transmission Intake Filter Test Procedure

RATIONALE

This document has been revised for greater clarity, simplification and to support advances in transmission intake filter technology and validation.

1. SCOPE

This test procedure is intended to apply to hydraulic pump suction filters and strainers used in automotive automatic transmissions that include hydraulic power pumps. The various paragraphs of Section 5, "Test Procedures," include a variety of tests and alternative tests that are not applicable to all filters and applications, so the engineer must specify which tests are to be performed for a particular application. These test procedures are intended to evaluate filter functional performance characteristics only, durability is not evaluated under this standard.

Filter design requirements must be specified by the engineer on the filter assembly drawing, an applicable engineering specification, or summarized on an application data sheet similar to that found in this recommended practice. See Figure 6, "Filter Assembly Application and Data Sheet."

Pressure circuit filters, both barrier and system contamination control types, are not covered under this standard. They are similar in design and construction to filters used in many hydraulic and lubricating applications.

1.1 Purpose

The purpose of this standard is to establish test methods to evaluate critical performance characteristics of automatic transmission intake (suction) filters. These filters need ratings for flow capacity, temperature range, contaminant capacity, filter efficiency and other critical functional characteristics. These characteristics should be representative of a production feasible design and are to be applied to the filter assembly. Pressure side filters are covered by other existing test standards and practices.

Prior use of "nominal" and "absolute" filter ratings as applied to a filter's ability to capture particles of a given size have been deprecated. This standard predicates the use of "Filtration Ratios" (efficiency) or "Beta Ratios" to describe the capture effectiveness under reproducible test conditions using a known test contaminant.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publication

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE HS806 Oil Filter Test Procedure

2.1.2 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 1219-1 Fluid power systems and components - Graphic symbols and circuit diagrams - Part 1: Graphic symbols for conventional use and data processing applications

ISO 3722 Hydraulic fluid power - Fluid sample containers - Qualifying and controlling cleaning methods

ISO 3968 Hydraulic fluid power - Filters - Evaluation of pressure drop versus flow

ISO 4021 Hydraulic fluid power - Particulate contamination analysis - Extraction of fluid samples from lines of operating systems

ISO 4405 Hydraulic fluid power - Fluid contamination - Determination of particulate contamination by gravimetric method

ISO 4406 Hydraulic fluid power - Method of coding level of contamination by solid particles

ISO 5598 Fluid power systems and components - Vocabulary

ISO 12103-1 Road vehicle - Test dust for filter evaluation - Part 1: Arizona test dust

ISO 11943 Hydraulic fluid power - On-line liquid automatic particle counting systems - Method of calibration and validation

ISO 11171 Hydraulic fluid power - Calibration of automatic particle counters for liquids

ISO 11841-1 Road vehicles and internal combustion engines - Filter vocabulary - Part 1: Definitions of filters and filter components

ISO 11841-2 Road vehicles and internal combustion engines - Filter vocabulary - Part 2: Definitions of characteristics of filters and their components

ISO 16889 Hydraulic fluid power - Filters - Multi-pass method for evaluating filtration performance of filter elements

2.1.3 Military Publication

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-H-5606G Fluid, Hydraulic – U.S. Military Specification: MIL-H-5606G

MIL-F-8815D Filter and Filter Elements, Fluid Pressure, Type II Systems, General Specifications

2.1.4 NFPA Publications

Available from the National Fluid Power Association, 3333 North Mayfair Road, Suite 211, Milwaukee, WI 53222-3219, Tel: 414-778-3344, www.nfpa.com.

NFPA T3.10.8.7 Hydraulic fluid power filter elements method for verifying flow fatigue characteristics

2.1.5 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org

ASTM MNL32 Manual on Test Sieving Methods: Guidelines for Establishing Sieve Analysis Procedures

ASTM C778-12 Standard Specification for Standard Sand

2.2 Other Publications - General Information References

2.2.1 Larkin, Larry; Boast, Andrew; Haggard, Dan and Khalil, Abrahim, SAE Publication AE-29, "Design Practices - Passenger Car Automatic Transmissions," Chapter 14, Filtration and Contamination Control

2.2.2 Eleftherakis, John G. and Khalil, Abrahim, "Development of Laboratory Test Contaminant for Transmissions", SAE Paper No. 900561

2.2.3 Eleftherakis, John G. and Khalil, Abrahim, "Advance Filter Test Methods - Utilizing the Multi-Pass Test," TAPPI Press, 1993

2.2.4 Eleftherakis, John G. and Khalil, Abrahim, "Test Methods for Automotive Filtration," SAE Paper No. 930016

2.2.5 Hummel, Paul A., "Advancements in Automotive Transmission Sump Filtration," SAE Paper No. 960535

3. TERMS AND DEFINITIONS

For the purpose of this document, the terms and definitions given in ISO 5598, ISO 11841-1, and ISO 11841-2 together with the following apply.

3.1 FILTER

A device whose primary function is to capture and retain insoluble contaminants from a fluid.

3.2 FILTER COMPONENTS

The parts that make up a filter.

3.2.1 Baffle

A device to prevent direct flow impingement or to guide the flow. Can be used inside the filter housing to prevent tunneling and channeling through the media by distributing the flow. When used on the outside of the filter, a baffle can prevent air ingestion during maneuvering or it can be used to guide spent fluid to the filter inlet.

3.2.2 By-Pass Valve

Used to allow fluid to by-pass the media, usually to give adequate flow under extreme cold conditions or where the filter is blocked by contamination. May be temperature or pressure regulated.

3.2.3 Cold Patch

A woven screen welded or otherwise placed over a by-pass opening in the filter media to improve fluid flow under extreme cold conditions.

3.2.4 Feet

Risers on the bottom of the filter to keep the filter housing off the sump pan and allow fluid flow to the filter inlet.

3.2.5 Grooving

Shallow ridges in the filter medium perpendicular to the roots of the pleats.

3.2.6 Housing

A ported enclosure which directs the flow of fluid through the filter element.

3.2.7 Internal Support

A permeable structural part which imparts rigidity to a filter element, and is primarily used to prevent filter element collapse.

3.2.8 Media

The porous layer of material that performs the actual particle interception, i.e., does the filtering.

3.2.9 Nozzle

A shaped port directed into the pump intake so as to supercharge the fluid entering the pump intake.

3.2.10 Outer Wrapper

A permeable enclosure, which protects the filter medium.

3.2.11 Pleats

A series of folds in the filter medium usually of uniform height and spacing, used to increase filter media area.

3.2.12 Root

The inner fold of a pleat.

3.2.13 Seal

A component or feature used to prevent cross media leakage or hydraulic short circuit thereby insuring leak free separation of hydraulic circuits.

3.2.14 Support

Part or feature used to provide support to the filter media so as to prevent collapse. May also be configured to act as a baffle to direct flow or prevent media damage from high velocity flow impingement.

3.3 FILTER ACCESSORIES

Auxiliary devices incorporated into a filter to enhance its usefulness.

3.3.1 Magnet

A magnet integrated into the housing which attracts and holds ferromagnetic particles.

3.3.2 Valve, Inertial Shuttle Inlet

A valve that moves in response to the forces associated with maneuvering, switching the fluid intake between two possible inlet openings so the inlet used is always submerged in fluid thereby preventing air ingestion.

3.3.3 Valve, Thermostatic

A valve that operates in response to a change in temperature, usually installed in a by-pass circuit to open and provide enhanced flow under cold conditions where the increased viscosity of the fluid prevents the fluid from moving readily through the filter media.

3.4 FILTER ELEMENT TYPES

Classification of filter elements by construction, application or method of filtration.

3.4.1 Intake Filter Element

A filter element, which is installed in the pump intake line.

3.4.2 Serial Filtration Media

Two or more media layers of different pore size used to capture and retain successively finer particles.

3.4.3 Strainer

A coarse filter element typically constructed from screen mesh.

3.4.4 Surface Element

A filter element that uses a woven or punched single layer filter element material with uniform hole sizes. The particle capture and retention mechanism is by straining or sieving of particles larger than the nominal hole size.

3.5 FILTER ELEMENT MEDIA

The porous materials, which performs the actual process of filtration.

3.5.1 Absorbent Media

A filter medium that holds contaminant by mechanical means.

3.5.2 Binder

Material applied to media during process, usually by dipping or spraying, to prevent media migration or shedding in use.

3.5.3 Combination Media

A filter medium composed of two or more types, grades, or arrangements of filter media to provide properties, which are not available in a single filter medium.

3.5.4 Depth Media

A thick media layer that uses adsorption and entanglement as the particle capture and retention mechanism.

3.5.5 Mesh

The count or number of mesh opening per linear distance in a woven filter cloth, e.g., "250 Mesh" indicates 250 openings per inch. Usually specified in inches, but may be specified in millimeters.

3.5.6 Non-Woven Media

A filter media composed of a random mat of fibers.

3.5.7 Woven Media

A filter medium made from strands of fiber, thread, or wire repetitiously interlaced into a cloth on a loom.

3.6 FILTER ELEMENT OPERATING MODE CONDITIONS

Conditions that may occur during operation of the filter throughout its useful life.

3.6.1 Artificially Loaded

A filter element that is loaded with a controlled laboratory test contaminant.

3.6.2 Bridging

A condition of filter element loading in which contaminant particles span the filter media pore openings blocking a portion of the useful filtration flow area.

3.6.3 Burst

An outward structural failure of the filter element caused by excessive differential pressure.

3.6.4 Caking

An accretion of contaminant or particulate that can result in reduced flow and at the same time increased filtration efficiency.

3.6.5 Clean

A new or properly cleaned filter element.

3.6.6 Collapsed

An inward structural failure of the filter element caused by excessive differential pressure.

3.6.7 Contaminated

A filter element which contains foreign particles resulting from handling, storage, or fabrication.

3.6.8 Dirty

A used filter element that is partially or completely loaded.

3.6.9 Fatigued

A structural failure of the filter medium due to flexing caused by cyclic differential pressure.

3.6.10 Loaded (Plugged)

A filter element that has collected a sufficient quantity of insoluble contaminants such that it can no longer pass rated flow without excessive differential pressure.

3.6.11 Pinched Pleat

A pleat closed off by excessive differential pressure or crowding, thus reducing the effective area of the filter element.

3.6.12 Ruptured

Any tear or split in the filter medium.

3.6.13 Service Loaded

A filter element, which is loaded from actual use.

3.6.14 Tunneling (Channeling)

Breakdown of the filter media caused by focused fluid flow; a hole or tear caused by high energy (kinetic or thermal) fluid stream.

3.7 FILTER PERFORMANCE

The following describe the functions and attributes of a filter or filter element.

3.7.1 Beta Ratio (Filtration Ratio)

A value calculated by measuring particle size concentration up and downstream of the filter assembly, used as an indicator of filter efficiency.

$$b_x = \frac{\text{Number of particles larger than X upstream}}{\text{Number of particles larger than X downstream}} \quad \text{(Eq. 1)}$$

3.7.2 Bubble Point

The differential gas pressure at which the first steady stream of gas bubbles are emitted from a wetted filter element under specified test conditions; a means to indicate the pore size.

3.7.3 Burst Pressure

The pressure which causes rupture. Also, the inside-out differential pressure that causes outward structural or filter medium failure of a filter element.

3.7.4 Burst Pressure Rating

The maximum specified inside-out differential pressure which can be applied to a filter element without outward structural or filter medium failure.

3.7.5 Collapse Pressure

The outside-in differential pressure that causes structural or filter medium failure of a filter element.

3.7.6 Collapse Pressure Rating

The maximum specified outside-in differential pressure which can be applied to a filter element without inward structural or filter medium failure.

3.7.7 Contaminant Capacity

There are two measures for Contaminant Capacity;

3.7.7.1 Injected Capacity

The weight of a specified artificial contaminant, which must be added to the influent to produce a given differential pressure across a filter at specified conditions.

3.7.7.2 Retained Capacity

The weight of particulate contaminant effectively retained by the filter element when Terminal Pressure is reached. This is an empirical value that can be calculated from test data by subtracting the weight of contaminant remaining in the test stand at the end of test from the Injected Capacity. The Retained Capacity may be used as an indication of the filter's relative service life.

3.7.8 Contaminant Migration

Contaminant, previously captured by the media, that has passed through the media, been released, and has proceeded downstream.

3.7.9 Differential Pressure (Pressure Drop)

The difference in pressure between the filter inlet and outlet due to fluid flow.

3.7.10 Effective Area

The total area of the porous medium in a filter element exposed to flow. Note that the flow through the media is usually not the same everywhere because of the proximity and configuration of the housing, flow distribution channels, media supports, and baffles and, as a result, some areas of the media may be less effective than other areas.

3.7.11 Efficiency

The ability, expressed as a percent, of a filter to remove a specified contaminant at a given contaminant concentration under specified test conditions.

3.7.12 Flow Fatigue

A structural failure of the filter medium due to flexing caused by cyclic flow.

3.7.13 Largest Particle Passed

The diameter of the largest hard spherical particle that will pass through a filter under specified test conditions (MIL-F-8815D).

3.7.14 Media Migration

Contaminant, in the form of filter media that has separated from its substrate, or manufacturing debris left in the filter assembly, that is released and proceeds downstream.

3.7.15 Open Area Ratio

The ratio of pore area to total area of a filter medium expressed as a ratio, fraction, or percent. This is applicable to woven or perforated filter media.

3.7.16 Permeability

The relationship of flow per unit area to differential pressure across a filter medium.

3.7.17 Pore Size Distribution

The ratio of the number of holes of a given size to the total number of holes per unit area expressed as a percent and as a function of hole size.

3.7.18 Porosity

The ratio of pore volume to total volume of a filter medium expressed as a percent. Applicable to depth media such as sintered or non-woven filter media.

3.7.19 Pressure Fatigue

A structural failure of the filter medium due to flexing caused by cyclic differential pressure.

3.7.20 Residual Contaminant Capacity

The contaminant capacity remaining in a service loaded filter element after use, but before cleaning, measured under the same conditions as the contaminant capacity of a new filter element.

3.7.21 Sloughing Off

The release of contaminant from the upstream surface of a filter element to the upstream side of the filter enclosure.

3.7.22 Terminal Pressure

That differential pressure required to produce a specified flow rate at a specified viscosity when the filter has reached its specified contaminant capacity.

3.7.23 Tortuosity

The ratio of the average effective flow path length to minimum theoretical flow path length (thickness) of a filter medium.

3.7.24 Total Area

The entire area of a porous media, whether effective or not, in a filter element.

3.7.25 Unloading

The release of contaminant that was initially captured by the filter media.

4. TESTS AND EQUIPMENT

4.1 Hydraulic Test Circuits

The circuits illustrated in Figures 1A and 1B are based on approved practice outlined in ISO 16889 to test filters operating at pressures above atmospheric - "Pressure Mode." These circuits are suitable for completing all tests in this recommended practice except "Pressure Drop vs. Flow Rating" at extreme cold temperatures, generally taken to mean temperatures below –20 °C. Figure 1A shows the preferred circuit for completing the 5.1.1 "Steady State Multi-Pass Efficiency" test, and Figure 1B shows the preferred circuit for completing the 5.1.2 "Pulsed Flow Efficiency" test. This is because they permit direct measurement of particle size concentration and distribution by automatic particle counters. Figures 2A and 2B illustrate circuits appropriate when test filter flow is compelled via atmospheric pressure – generally known as "Suction Mode." These circuits are likewise suitable for evaluating "Steady State Multi-Pass Efficiency" (Figure 2A) and "Pulsed Flow Efficiency" (Figure 2B); however, this alternate method infers influent contaminant concentration via reservoir sampling in lieu of upstream and downstream particle counting. Both methods, "Pressure Mode" or "Suction Mode," require validation in accordance with procedures outlined below (see 4.4.7.3 "Validation"). For either method, the Test Stand supply must be capable of producing sufficient flow, controlling temperature and pressure, and maintaining the test contamination in suspension throughout the test.

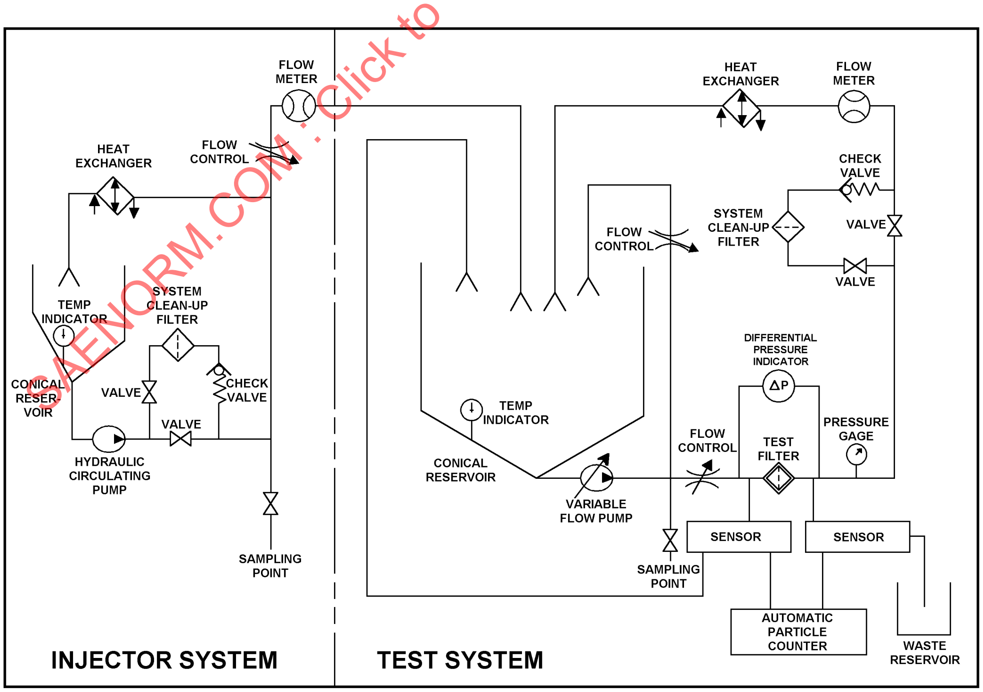

FIGURE 1A - TYPICAL INTAKE FILTER TEST CIRCUIT: PRESSURE MODE, STEADY STATE MULTI-PASS TEST

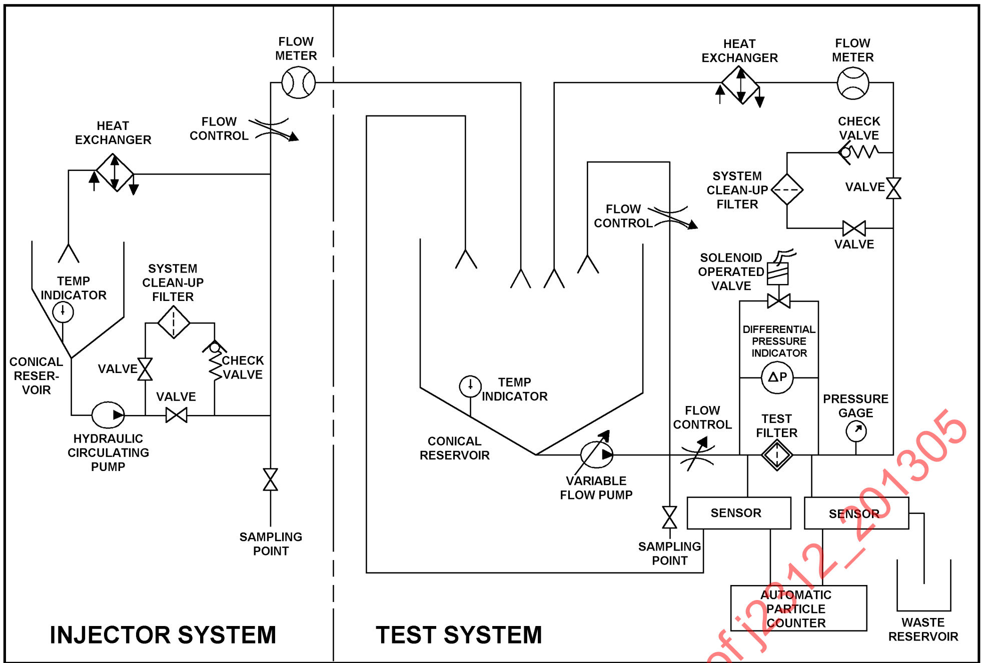

FIGURE 1B - TYPICAL INTAKE FILTER TEST CIRCUIT: PRESSURE MODE, PULSED FLOW EFFICIENCY TEST

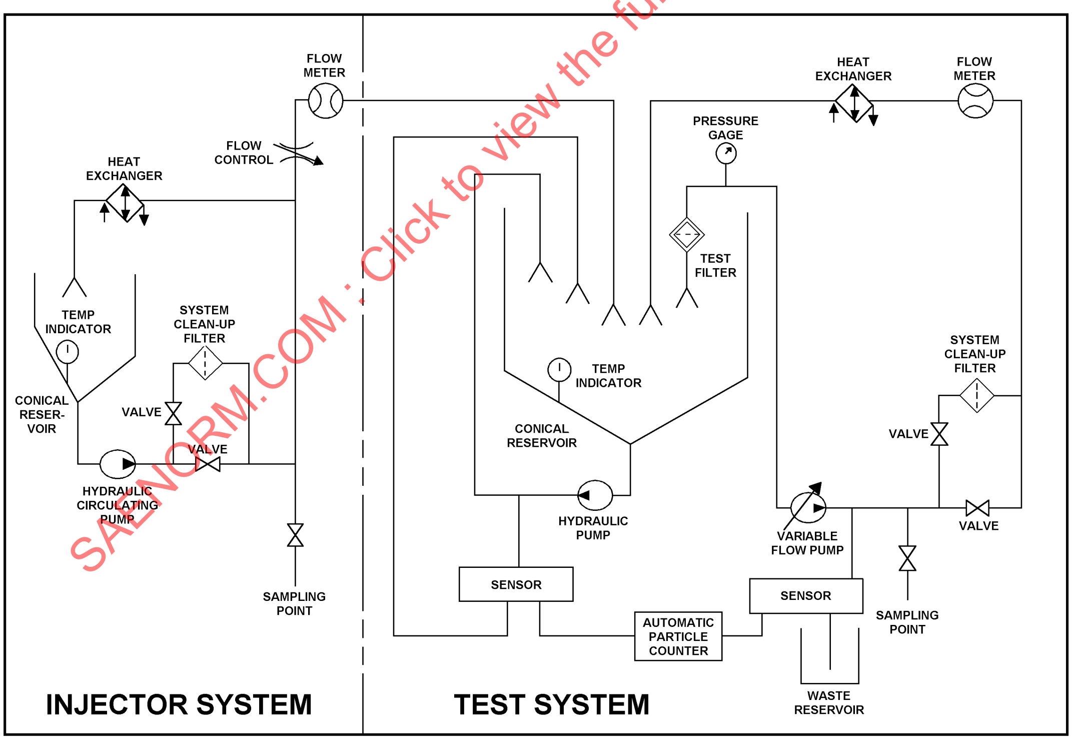

FIGURE 2A - TYPICAL INTAKE FILTER TEST CIRCUIT: SUCTION MODE, STEADY STATE MULTI-PASS TEST

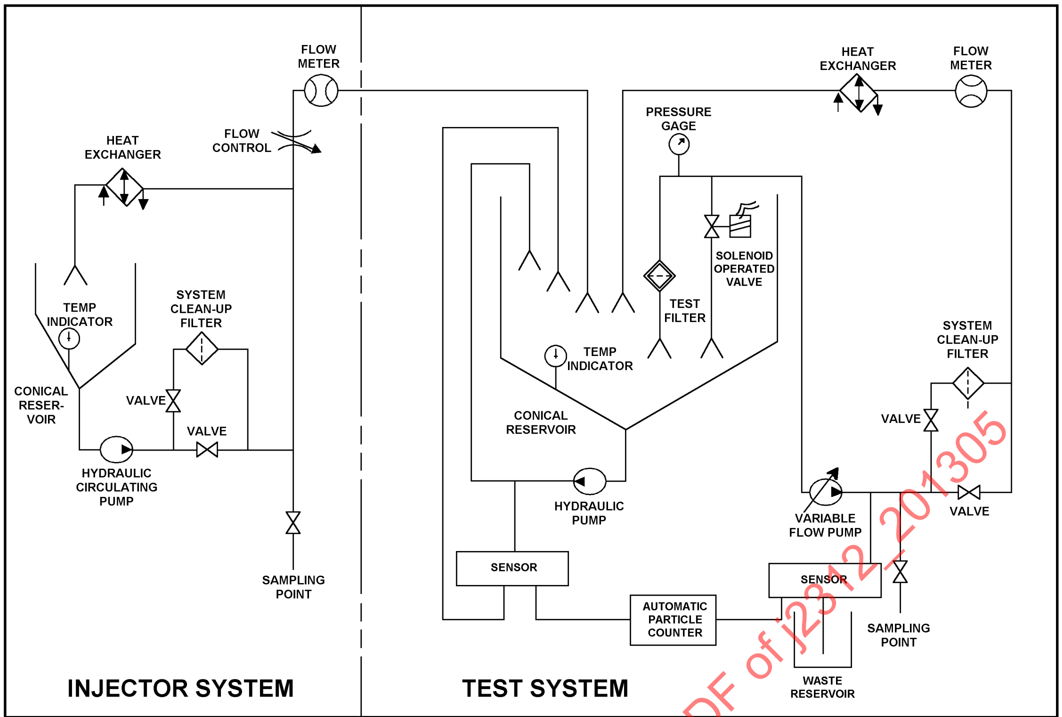

FIGURE 2B - TYPICAL INTAKE FILTER TEST CIRCUIT: SUCTION MODE, PULSED FLOW EFFICIENCY TEST

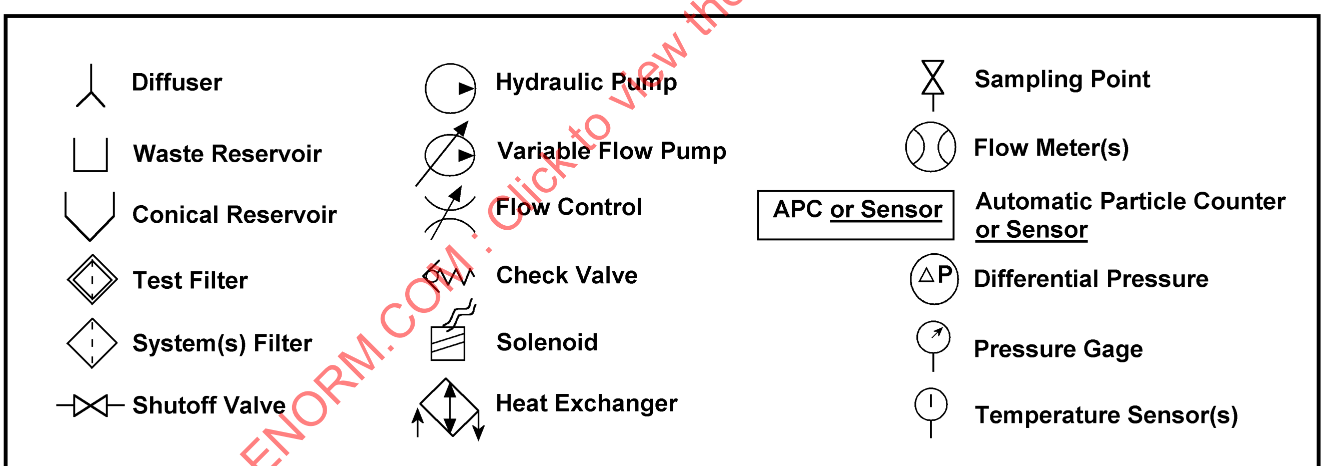

FIGURE 3 - HYDRAULIC SCHEMATIC LEGEND

NOTE: All equipment, test stand circuits, measuring devices and data acquisition equipment must be certified in accordance with ISO 16889, ISO 11943 and ISO 11171. This Hydraulic Schematic Legend is applicable to all schematics found in this document.

4.2 Test Fluid

4.2.1 Filter Pressure Drop Test

Shall be conducted using the transmission manufacturer's specified fluid, i.e., the fluid intended to be used for "Factory Fill" for the subject application. Fluid cleanliness level and the test method for fluid cleanliness verification must be specified. Alternative Automatic Transmission Fluid (ATF) meeting the "Factory Fill" specifications with viscosity-temperature match may also be used.

4.2.2 Filter Efficiency and Contaminant Rating Tests

Shall be conducted using MIL-H-5606 G Hydraulic Fluid to establish standard rating for test dust capacity, media migration and filter efficiency. Alternative fluids meeting the specifications of ISO 16889, Paragraph 6.6 "…petroleum base test fluid…" may also be used. Automatic Transmission Fluid (ATF) is not appropriate for use in this test due to its high viscosity and opacity.

4.3 Test Contaminants

Test contaminants may be divided into three major categories that include test dust, metal powders and special test contaminants that have a documented formulation. Based on the specified filtration test (e.g., efficiency, capacity, etc.) and the specifications to which these tests are being conducted, one or more categories of test contaminants may be utilized in the following Filter Assembly Multi-Pass test procedures. A description of the test contaminants and their test use follows. The Intake Filter Assembly Test Report, Steady State Multi-Pass Efficiency Test (see Figure 4) must indicate the formulation, identification, originating laboratory, governing standard, particle size distribution, and material content.

4.3.1 Test Dust

In accordance with ISO 12103-1, test dusts are usually manufactured from Arizona desert sand which is a naturally occurring contaminant consisting primarily of silicon dioxide and other compounds. These test dusts are abrasive in nature and are commonly found as contaminants in motor vehicle power trains. Arizona desert sand has a density of approximately 2650 kg/m^3. Generally, Arizona Test Dust is used in multi-pass filtration efficiency tests and capacity tests. Arizona Test Dusts are classified into four standard grades described in Table 1, "Test Dust Classification."

NOTE: Paragraph 4.3.1.1 describes how to make dry test dust stock from bulk material. This stock will be used (added) to the hydraulic test system to achieve particle concentrations found in Table 3A and 3B, "Acceptable Cumulative Particle Counts per 100 mL."

TABLE 1 - TEST DUST CLASSIFICATION

ISO Designation	Description	Approx. Bulk Density
ISO 12103-1 A1 Ultrafine	0 – 20 µm Test Dust	500 kg/m^3
ISO 12103-1 A2 Fine	0 – 80 µm Test Dust	900 kg/m^3
ISO12103-1 A3 Medium	0 – 120 µm Test Dust	1025 kg/m^3
ISO 12103-1 A4 Coarse	0 – 200 µm Test Dust	1200 kg/m^3

4.3.1.1 For pulsed flow efficiency tests, the preferred test contaminant is Coarse Sieved Grade (140 to 300 µm) graded silica grains, sieved and calibrated in accordance with ASTM C778.

Preparation of the mix is as follows:

Use ASTM C778 graded silica grains. The test contaminant consists of two parts, each contributing to the final mix, 50% by weight. Pass the stock material through a 514 µm screen, then through a 250 µm screen. All material captured on the 250 µm screen is to be used for part 1. Material that has passed through the 250 µm screen should then be passed through a 150 µm screen. All material remaining on the 150 µm screen is to be used for part 2.

4.3.1.2 For Multi-Pass Efficiency Tests, the preferred test contaminant is the ISO 12103-1 A4, “Coarse” test dust.

Test Lab	Test Date	Tech

Filter Assembly Part No.	Rev Level & Date Test ID No

Test Conditions

Test Fluid ______	Supplier _______	Test Temperature _______
Test Contaminant Type_______	Supplier _______	Certification
Test System – Main Flow Rate _______ Base Upstream Concentration Level *(See Table 2 “Test Condition Values” for specification)*	Initial Volume _________	Final Volume______

Injection System

Injection System Parameters	Initial	Final	Average Injection Parameters		
System Volume (l)			Injection Flow (l/min)	________	______
Concentration (mg/l)			Concentration (mg/l)	________	______

Counting System	Counter and Sensor Ref	Flow Rate (l/min)	Dilution Ratio
Upstream			
Downstream			
Counter Calibration	Method	Date	

FIGURE 4A - TYPICAL INTAKE FILTER ASSEMBLY TEST REPORT STEADY-STATE MULTI-PASS EFFICIENCY TEST

Differential Pressure								
Filter Assembly-Clean				Filter Assembly - Terminal				
Differential Pressure versus Contaminant added								
Time Interval	Test Time (elapsed time) (min)	Assy Diff Press (kPa)	Injected Mass (g)		Time Interval	Test Time (elapsed time) (min)	Assy Diff Press (kPa)	Injected Mass (g)
10%					60%			
20%					70%			
30%					80%			
40%					90%			
50%					100%			
Retained Capacity								
Contaminant Mass Injected ____________ g					Contaminant Mass Retained _____ g			
Upstream Gravimetric Level @ 80% ____________ mg/l								

FIGURE 4B - INTAKE FILTER ASSEMBLY TEST REPORT STEADY-STATE MULTI-PASS EFFICIENCY TEST

Test Time Interval		> 20	Beta	> 30	Beta	> 40	Beta	> 50	Beta	> 60	Beta	> 70	Beta	> 80	Beta	> 100	Beta
Initial Upstream																	
10%	Upstream																
	Downstream																
20%	Upstream																
	Downstream																
30%	Upstream																
	Downstream																
40%	Upstream																
	Downstream																
50%	Upstream																
	Downstream																
60%	Upstream																
	Downstream																
70%	Upstream																
	Downstream																
80%	Upstream																
	Downstream																
90%	Upstream																
	Downstream																
100%	Upstream																
	Downstream																
Avg. Upstream																	
Avg. Downstream																	
Avg. Beta																	
Avg. Efficiency																	

FIGURE 4C - INTAKE FILTER ASSEMBLY TEST REPORT STEADY-STATE MULTI-PASS EFFICIENCY TEST

4.3.2 Metal Powders

4.3.2.1 Synthetic Formulations

Synthetic formulations constituted with a particle size distribution and material content as specified by the design engineer and accompanied by laboratory certified distribution may be used in tests of filter assemblies including those that have an auxiliary means of particle capture and retention.

4.3.2.2 Iron Based Powder Metal (PM) Base Stock

For special tests that require metal powders of known particle size distribution and chemical content to test auxiliary means of particle capture such as magnets, specially prepared contaminants may be used. Laboratory certification of particle size distribution and material content shall be obtained.

4.3.3 Other Contaminants

Other contaminants not specified herein may be used for testing under this recommended practice. However, all test results must be accompanied by an "Intake Filter Assembly Test Report, Steady State Multi-Pass Test" (see Figure 4), and/or an "Intake Filter Assembly Test Report, Pulsed Flow Test" (see Figure 5) indicating the formulation identification, originating laboratory, governing standard, particle size distribution, and material content.

4.4 Test Equipment

Suitable test circuits that have proved successful are illustrated in Figure 1A and 2A. Related equipment not illustrated which may be useful or necessary is described below.

4.4.1 Timer

Use a suitable timer for measuring time.

4.4.2 Particle Counter(s)

Use an automatic particle counter(s) calibrated in accordance with ISO 11171.

4.4.3 Test Contaminants

Use the test contaminant specified by the test requester. If different from those test contaminants listed in 4.3 "Test Contaminants," the requester must provide full definition to include particle size concentration and distribution. Dry the contaminant in an oven at 110 °C for not less than 1 h for quantities less than 200 gm and for use in the test system. Mix in the test fluid. Mechanically agitate then disperse ultrasonically with a power density of 3000 W/m^3 to 10,000 W/m^3.

4.4.4 Particle Counting

Use an online particle counter (see 4.4.2), with a dilution system if necessary, that has been validated in accordance with ISO 11943.

4.4.5 Sample Bottles

Bottle samples should be used for gravimetric analysis only. Online particle counting is the preferred method. However, for gravimetric analysis, use super clean sample bottles containing less than 20 particles per mL of bottle volume greater than 6 µm as qualified per ISO 3722, "Hydraulic Fluid Power – Fluid Sample Containers – Qualifying and Controlling Cleaning Methods."

Test Lab	Test	Date	Tech

Filter Assembly Part No.	Rev Level & Date Test ID

Test Conditions

Test Fluid	Supplier	Test Temperature
Test Contaminant Type	Supplier	Certification
Test System - Main Flow Rate Base Upstream Concentration Level *(See Table 2 "Test Condition Values" for specification)*	Initial Volume	Final Volume

Injection System

	Batch No.	1	2	3	4	5	6	7	8
Batch Weight	(g)								
Batch Sieve Date									

Test Results

Differential Pressure

Filter Assembly-Clean	Filter Assembly - Terminal

Differential Pressure versus Contaminant added

Time Interval	Test Time (elapsed time) (min)	Assy Diff Press (kPa)	Injected Mass (g)	Time Interval	Test Time (elapsed time) (min)	Assy Diff Press (kPa)	Injected Mass (g)
10%				60%			
20%				70%			
30%				80%			
40%				90%			
50%				100%			

Retained Capacity

Contaminant Mass Injected ____________ g Contaminant Mass Retained ________ g

Upstream Gravimetric Level @ 80% ____________ mg/l

FIGURE 5A - TYPICAL INTAKE FILTER ASSEMBLY TEST REPORT - PULSED FLOW TEST

Particle Counts (particle per ml) and Beta Ratio

No. **Test ID**

Test Time Interval		> 140	Beta	>160	Beta	>180	Beta	>200	Beta	> 220	Beta	>240	Beta	>260	Beta	> 280	Beta
Initial Upstream																	
10%	Upstream																
	Downstream																
20%	Upstream																
	Downstream																
30%	Upstream																
	Downstream																
40%	Upstream																
	Downstream																
50%	Upstream																
	Downstream																
60%	Upstream																
	Downstream																
70%	Upstream																
	Downstream																
80%	Upstream																
	Downstream																
90%	Upstream																
	Downstream																
100%	Upstream																
	Downstream																
Avg. Upstream																	
Avg. Downstream																	
Avg. Beta																	
Avg. Efficiency																	

FIGURE 5B - INTAKE FILTER ASSEMBLY TEST REPORT - PULSED FLOW TEST

TABLE 2 - TEST CONDITION VALUES

Test Conditions[1] Base upstream gravimetric, mg/l[1][2]	Condition 1[3] For small or high efficiency filters. 10 mg/l ± 2.0 mg/l	Condition 2[3] For large or coarse filters. 25 mg/l ± 3.0 mg/l
Initial contamination level for Main filter test system)	Less than 1% of the minimum specified in Table 3A or 3B Measured at the minimum particle size to be counted.	Less than 1% of the minimum specified in Table 3A or 3B Measured at the minimum particle size to be counted.
Initial contamination level for injection system	Less than 1% of injection gravimetric level.	Less than 1% of injection gravimetric level.
Recommended particle counting sizes[4]	Minimum of five sizes selected to cover the presumed filter performance range from Beta = 2 to Beta =200. Typical sizes are 6, 10, 14, 20, 30, 40, 50, & 60 µm.	Minimum of five sizes selected to cover the presumed filter performance range from Beta = 2 to Beta =200. Typical sizes are 20, 30, 40, 50, 60,70,80 & 100 µm.
Sampling and counting method	Online automatic particle counting	Online automatic particle counting

1. This table lists two contamination concentration levels. Test Condition 1 may be used for small or high efficiency filters. Test Condition 2 may be used for large or coarse filters. Test Contaminant Concentration has a significant impact on reported efficiency, capacity and test duration. Concentrations should be selected such that test duration is at least 30 min. The test requester must specify which Test Condition to use.
2. When comparing test results between two filters, the base upstream gravimetric level should be the same.
3. To establish particle size distribution, especially for Coarse Sieved contamination, see 4.3.1.1 and 4.3.1.2 regarding preferred test contaminants and the procedures described therein for qualifying the particle size distribution. Also see the note following Table 3B.
4. Particle size counts where filter beta ratings high (Beta = 200 or greater) may be unobtainable for coarse filters.

TABLE 3A - ACCEPTABLE CUMULATIVE PARTICLE COUNTS PER 100 mL FOR STEADY STATE MULTI-PASS OR PULSED FLOW EFFICIENCY TESTS, ISO COARSE TEST DUST (5 TO 200 µm)

Particle Size (microns)	Test Condition 1 Min	Test Condition 1 Max	Test Condition 2 Min	Test Condition 2 Max
20	3000	6000	4500	9000
40	1000	2000	1500	3000
60	500	1000	750	1500
80	200	400	300	600
100	50	100	75	150
120	50	100	75	150
140	50	100	75	150

TABLE 3B - ACCEPTABLE CUMULATIVE PARTICLE COUNTS PER 100 mL FOR PULSED FLOW EFFICIENCY TESTS, COARSE SIEVED GRADE (50/50 MIX; OF 150 TO 250 µm, AND 250 TO 500 µm)

Particle Size (microns)	Test Condition 1 Min	Test Condition 1 Max	Test Condition 2 Min	Test Condition 2 Max
140	1000	2500	1500	3750
160	600	1500	900	2250
180	300	750	450	1125
200	200	500	300	750
220	200	500	300	750
240	100	250	150	375
260	100	250	150	375
280	50	125	75	188
300	50	125	75	188

NOTE: High filter efficiency claims require a sufficient concentration of particles at the claimed micron size in the fluid to insure the filter media is adequately challenged, e.g., a claim of Beta = 100 at 200 µm requires a minimum concentration of 1000 particles at 200 µm.

4.4.6 Test Fluid

Use petroleum based test fluid with properties as detailed in ISO 16889. MIL-H-5606-G is one such fluid and is usually used. This fluid has worldwide availability and, because its manufacture is carefully controlled, its use assures greater reproducibility. It is also the fluid of choice in most other generally accepted filter test standards.

4.4.7 Test Circuits

The test circuits illustrated in Figures 1A and 2A are suitable for steady state contamination test and pressure drop tests. For more detailed information, refer to ISO 16889. Additional test circuits are described and illustrated in 4.4.8 of that standard and shown in figures referenced there.

4.4.7.1 Filter Test Circuit, Filter Efficiency, Capacity and Pressure Drop Test.

a. Use a reservoir, pump, fluid conditioning apparatus and instrumentation that are capable of accommodating the range of flows, pressures, and volumes required by the procedure, and is capable of meeting the validation requirements of 4.4.7.3.

b. Use a cleanup filter capable of providing an initial system contamination level as specified in Table 2, "Test Condition Values."

c. Use a configuration that is relatively insensitive to the intended operative contaminant level.

d. Use a configuration that will not alter the test contaminant distribution over the anticipated test duration.

e. Use pressure taps in accordance with ISO 3968.

f. Use fluid sampling section upstream and downstream of the test filter in accordance with ISO 4021.

g. Outlet diffuser nozzle(s) shall be located below the fluid surface and all piping shall be designed to result in turbulent flow.

h. For "Suction Mode" circuits (see Figure 2A) the following additional requirements apply:

    1. The Main Reservoir must have a fluid circulation system consisting of a pump, piping and outlet diffuser of appropriate design to provide one to two complete reservoir fluid changes per minute.

    2. The upstream automatic particle counter shall be fed from a pressure tap in the re-circulation system.

    3. The test filter will be located in the Main Reservoir, below the surface of the fluid, and fixtured in the same orientation as found in the vehicle.

NOTE: Manual sampling, i.e., "bottle sampling," is not suitable for particle counting and should be used for gravimetric analysis only. For bottle sampling, quarter-turn ball valves must be used. For particle counting devices, suitable sample connectors must be fitted at the filter inlet and outlet connections. These connectors must be in accordance with ISO 4021 "Hydraulic Fluid Power - Particulate Contamination Analysis; Extraction of Fluid Samples from Lines of Operating Systems." These fittings are specially designed to permit sampling of fluid at reduced flow rates without collecting test contaminant themselves and thus affecting the particle concentration and distribution.

4.4.7.2 Contaminant Injection System (Filter Efficiency Tests only)

a. Use a reservoir, pump, fluid conditioning apparatus and instrumentation that are capable of accommodating the range of flows, pressures, and volumes required by the procedure, and are capable of meeting the validation requirements of 4.4.7.3.

b. Use a configuration that is relatively insensitive to the intended operative contaminant level.

c. Use a configuration that will not alter the test contaminant distribution over the anticipated test duration.

d. Fluid sampling section shall be in accordance with ISO 4021. See “NOTE” in 4.4.7.1.

4.4.7.3 Filter Test System and Contaminant Injection System Validation

For test stands operated as illustrated in Figure 1A “Intake Filter Test Circuit - Pressure Mode,” or Figure 2A “Intake Filter Test Circuit - Suction Mode”, test stand validations must be in accordance with ISO 16889, section 8.0. Regardless of test method, test stand validation must be verified no less than once per calendar quarter.

4.4.8 Additional Test Circuits

4.4.8.1 Additional test circuits are illustrated in Figure 1B, “Typical Intake Filter Test Circuit: Pressure Mode, Pulsed Flow Efficiency Test”, and Figure 2B, “Typical Intake Filter Test Circuit: Suction Mode, Pulsed Flow Efficiency Test”. The following requirements apply:

a. The requirements contained in 4.4.7.1 a. through h. including the capability of meeting the validation procedures 4.4.7.3.

b. The pulse control circuit (bypass circuit) must produce a time response such that the first time constant for the required flow amplitude defined on the Filter Application and Data Sheet (see Figure 6) is less than 200 ms. See Figure 7A, “Pulsed Flow Efficiency Test: Typical Pulsed Flow Profile”, and Figure 7B, '' Pulsed Flow Efficiency Test: Typical Pulsed Flow Profile Rise and Fall Rate Guidance ''.

c. Equipment and circuit connections illustrated in Figure 1B are essentially identical to Figure 1A, “Steady State Multi-Pass Efficiency Test” except a bypass valve is added to achieve rapid acceleration and deceleration of flow through the test filter. The Main Reservoir pump capacity may need to be greater than that required for “Steady State Multi-Pass Tests.”

d. Equipment and circuit connections illustrated in Figure 2B are essentially identical to Figure 2A, “Suction Mode, Steady State Multi-Pass Test” except a bypass valve is added to achieve rapid acceleration and deceleration of flow through the test filter. The Main Reservoir pump capacity may need to be greater than that required for “Steady State Multi-Pass Tests.”

4.4.8.2 Extreme Cold Temperature Equipment

The equipment used for these tests is intended to establish flow and pressure drop relationship only. No contamination testing is intended to be completed with this equipment. See Figures 8A and 8B.

a. Use a reservoir, pump, (accumulator or cylinder rigged to compel flow through the filter) appropriate controls, fluid conditioning apparatus and instrumentation that are capable of accommodating the range of flows, pressures, and volumes required by the procedure.

b. Thermal enclosure and heat transfer equipment must not create localized cold or hot areas in excess of ±2 °C (±4 °F).

c. Flow measurement devices must be capable of discerning presence of undissolved air or be a mass flow meter. It must be intended for extreme temperature and fluid viscosity and able to be calibrated for use under these conditions. The flow meter must not be located between test filter and pressure gauge.

d. Test Fluid should be “Factory Fill” ATF with verification that water content and cleanliness meet factory specifications. Undissolved air must be absent at Standard Temperature and Pressure (STP).

e. If operated in “Suction Mode,” see Figure 8A, an alternative to flow measurement may include measurement of cylinder displacement (movement) with appropriate signal conditioning and algorithms to indicate flow rate and total volume passed.

f. If operated in “Pressure Mode,” see Figure 8B, test filter must be installed in a rigid leak free test fixture (sealed housing) and differential pressure must be measured.

g. If a test circuit illustrated in Figure 8B is used, the cold reservoir must be of sufficient size to provide a controlled rise in flow from zero to rated cold flow.

h. All instrumentation must be capable of operation at the temperature and fluid characteristics encountered under these tests, and such parameters defined in the equipment’s ratings.

Filter Design / Application Data Sheet

Filter Part No.	**Program:**
Filter Manufacturer	**Description:**

Parameter	ES-SPEC/ SDS PARA. NO.	Sample Size	Acceptance Criteria		Reference			Last Change Date/Initials
			Parameters	Reliability	Procedure	FMEA Para. No.	DVP & R	
Application								
Vehicle Line								
Transmission Models								
Engine(s)								
Factory Filled Fluid								
Ratings - Filter Assembly (Housing & Element)								
(See note 1) * Load Capacity - ISO 12103-1A 4								
(See note 1) * Load Capacity - Metalic Compound								
(See note 1) * Terminal Pressure Drop								
(See note 1) * Beta Rating								
(See note 1) * Media Migration								
(See note 2) * Flow - Clean Element - -18C @ .035 kPa diff								
(See note 2) * Flow - Clean Element - +100C @ .035 kPa diff								
(See note 1) * Pulsed Flow - min flow								
(See note 1) * Pulsed Flow - max flow								
(See note 1) * Pulsed Flow - Duration at min flow								
(See note 1) * Pulsed Flow - Duration at max flow								
(See note 1) * Pulsed Flow - time constant								
(See note 2) * Max Rated Inlet Temperature								
(See note 2) * Max Inlet Over Temperature								
Ratings: Valve (if equipped)								
Drain Back								
Bypass Valve								
* Cracking Pressure								
* Max kPa diff @ flow rate								
Max Rated Flow								
Environmental / Mounting / Service								
Service Interval								
Hydraulic Fatigue								
* Shell								
* Seal - Fretting								
* Seal - Creep								
* Crimp								
Proof Pressure								
Crush - peripheral								
Crush - Normal								
High Temp Endurance								

Notes: 1. Performance test using MIL 5606 or equivalent
2. Performance test with Factory Fill Fluid

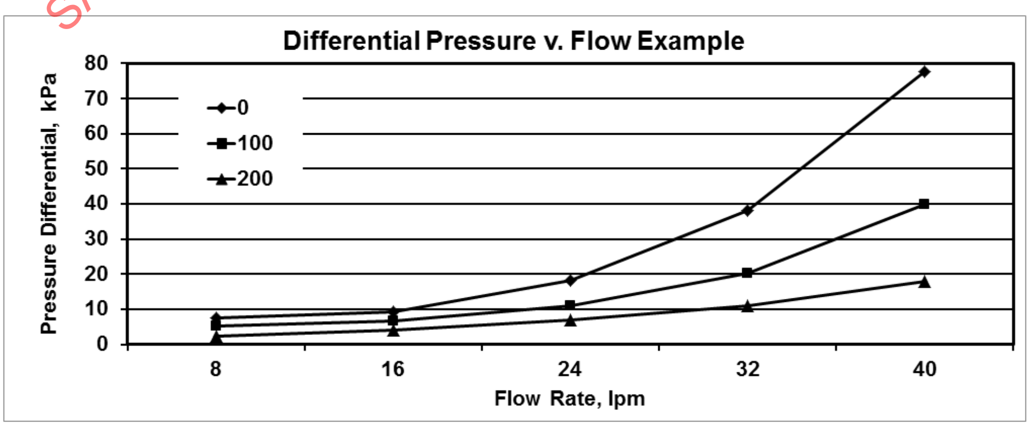

FIGURE 6 - FILTER DESIGN/APPLICATION DATA SHEET

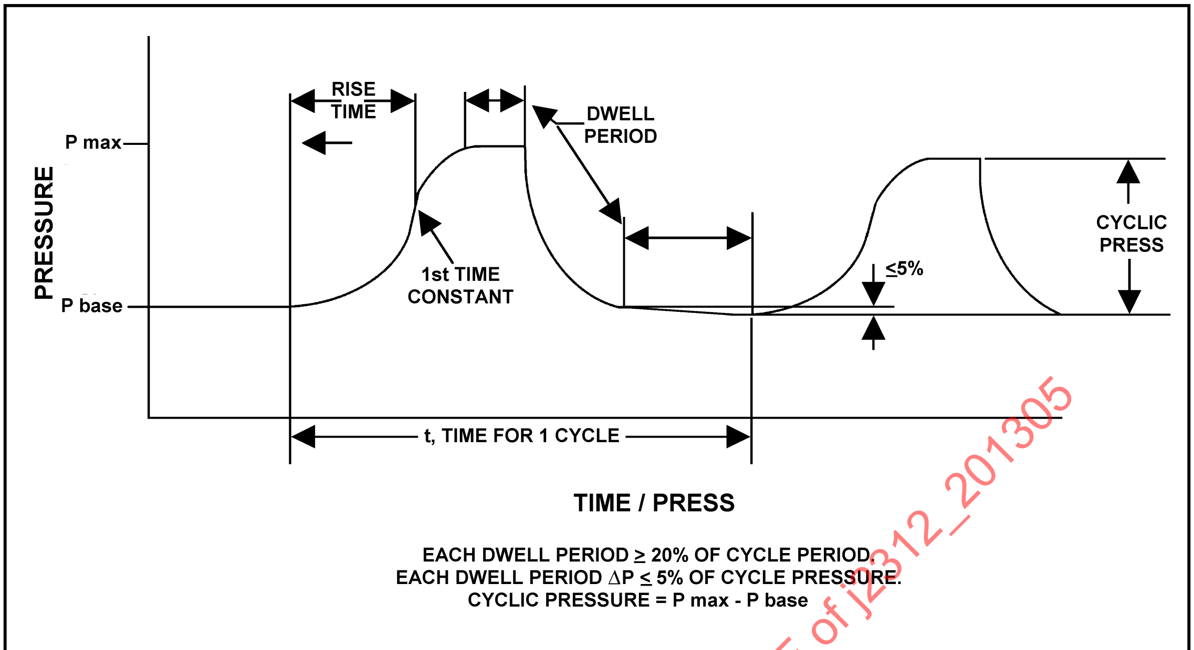

FIGURE 7A - PULSED FLOW EFFICIENCY TEST: TYPICAL PULSED FLOW PROFILE

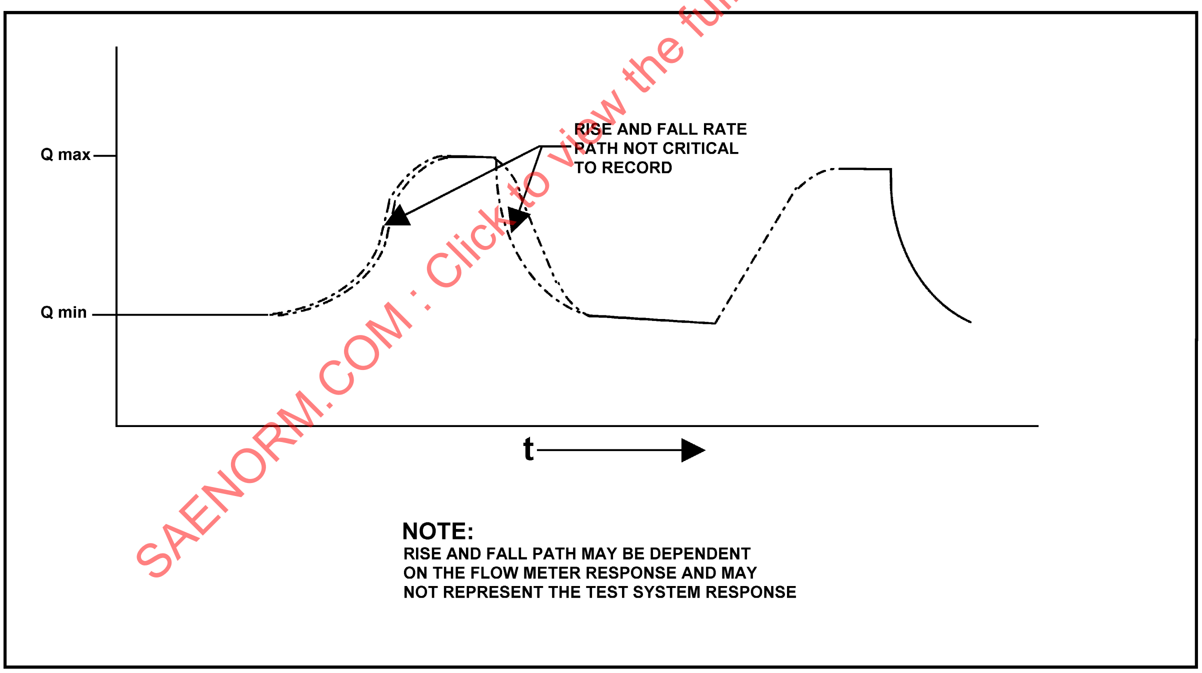

FIGURE 7B - PULSED FLOW EFFICIENCY TEST: TYPICAL
PULSED FLOW PROFILE RISE AND FALL RATE GUIDANCE

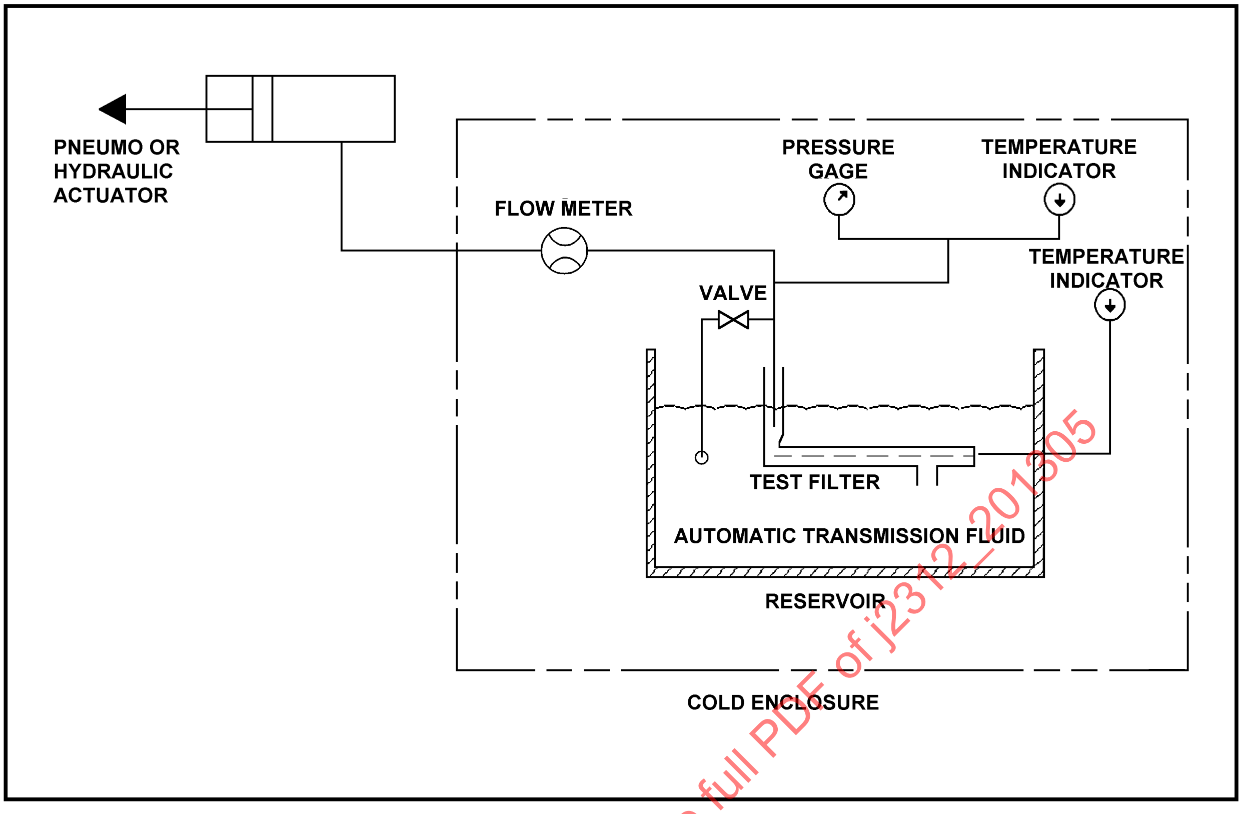

FIGURE 8A - EXTREME COLD TEMPERATURE TEST CIRCUIT: SUCTION MODE

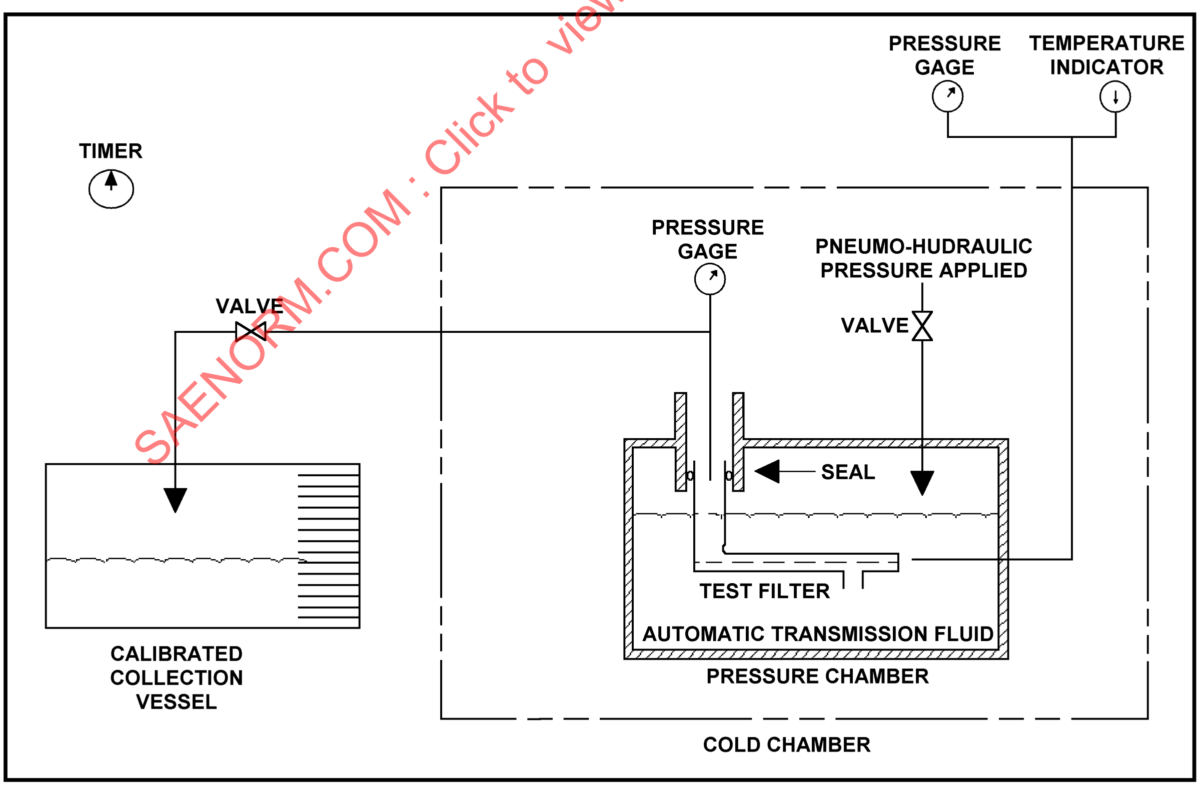

FIGURE 8B - EXTREME COLD TEMPERATURE TEST CIRCUIT: PRESSURE MODE

4.5 Equipment for Gravimetric Analysis

(For reference, see ISO 4405.)

4.5.1 Filter analysis patch (analytical membrane filters), white, plain, 47 mm OD, 0.8 µm and 5 µm pore sizes.

4.5.2 Filter holder, 47 mm of borosilicate glass or stainless steel funnel and funnel base, plus clamps (2), aspiration flask, and stainless steel trays, and rubber stoppers.

4.5.3 Analytical balance accurate to 0.0001 g.

4.5.4 Petri dishes, 60 mm ID

4.5.5 Non-circulatory air oven for 100 °C

4.5.6 Forceps, flat bladed (3)

4.5.7 Wipes, lint free

4.5.8 Squirt bottles or pressurized spray tank with gun

4.5.9 Washing and storage bottles

4.5.10 Desiccator

4.5.11 Gloves, particulate free impermeable

4.5.12 Vacuum system capable of achieving 380 mm Hg vacuum.

4.5.13 Solvent, filtered to 1 µm - petroleum based with flash point at 60 °C or higher is preferred, e.g., Stoddard solvent P-D-680 Type IIA, or naphtha D-60.

4.6 Data Acquisition System

The data acquisition system for filter tests described in this document should be capable of monitoring and recording all input variables. This includes but is not limited to signals relating to time, pressures, particle counts, temperatures, flow rates and miscellaneous electrical signals which translate into specific parameters such as liquid level. The system should be capable of monitoring and recording data from both normal system operation mode and from calibration or validation mode. Data acquisition should have the capability of no less than 10,000 counts per second for any single channel.

5. TEST PROCEDURES

5.1 Filtration Efficiency

Applicable to Filter Assembly or Media Test fixture.

5.1.1 Steady-State Multi-Pass Test

5.1.1.1 Test Preparation

Use a data sheet similar to that illustrated on Figure 4 “Filter Assembly Test Report – Steady State Multi- Pass Test.” Complete all pertinent blocks and record all test results on this form.

NOTE: This test report form is similar to and is based on the test report form found in ISO 16889, "Hydraulic Fluid Power – Multi-Pass Method for Evaluating Filtration Performance of Filter Elements." For more clarification and explanation, see that standard.

Install an empty housing (no filter element) and circulate test fluid through the Main Reservoir and test circuit to purge all air. Adjust test parameters to the conditions listed in Table 4 "Steady State Multi-Pass Efficiency Test Parameters." When system temperature has reached 38 °C (kinematic viscosity of 15 mm^2/s), circulate for 15 min and establish system cleanliness by using the upstream and downstream particle counters. Verify that the initial cleanliness level is within 1% of the required level and record. (See Table 2, "Test Condition Values" for specification of level, and Figure 4, "Filter Assembly Test Report, Steady State Multi-Pass Test" for where recorded).

5.1.1.2 Test Initiation

Install the test filter assembly into the test circuit. Start the circuit flow and verify that all test parameters are in accordance with those in Table 4.

NOTE: Unless specified otherwise, use the values specified in Table 4. These test parameters are designed to permit completion of the test in a reasonable period of time. If small filters with large pore size (coarse media) exhibit prolonged loading characteristics, Test Condition 2 may be used. Conversely, if large filters with small pore media exhibit rapid loading characteristic that inhibit data repeatability, Test Condition 1 may be used.

TABLE 4 - STEADY STATE MULTI-PASS EFFICIENCY TEST PARAMETERS

Terminal Differential Press	Test Fluid	Test Temp	Filter Size (Media area – cm^2)	Flow rate Steady State	Test Condition (Concentration See Table 2)	Contaminant Recommended
66 kPa	MIL H 5606-G	38 °C	Up to 250 cm^2	10.0 L/min	1	ISO 12103-1 A4
66 kPa	MIL H 5606-G	38 °C	250-500 cm^2	20.0 L/min	1	ISO 12103-1 A4
66 kPa	MIL H 5606-G	38 °C	500-1000 cm^2	20.0 L/min	2	ISO 12103-1 A4
66 kPa	MIL H 5606-G	38 °C	1000 cm^2 and larger	20.0 L/min	2	ISO 12103-1 A4

5.1.1.3 Pressure Calculation

Unless specified on the Filter Assembly Application and Data Sheet, calculate the test filter assembly Terminal Pressure by multiplying the Filter Assembly rated Differential Pressure by 80%.

5.1.1.4 Measure and record the initial system contamination level using the on line particle counter from upstream of the test filters.

5.1.1.5 Obtain a bottle sample from the contamination injection system and label "Initial Injection Gravimetric Sample."

5.1.1.6 Measure and verify the injection flow rate, and record.

NOTE: Continuous measurement of the injection flow rate is required throughout the test to ensure the flow is maintained within the specified tolerance.

5.1.1.7 Start of Test

Initiate the filter test by opening the injection reservoir shutoff valve, (injection begins), starting the timer, and diverting the downstream sample flow to maintain a constant Main Reservoir volume (±5%).

5.1.1.8 Measurements During Test

Conduct and record upstream and downstream particle counts at equal time intervals not to exceed 1 min, until the differential pressure across the filter assembly has increased to the Terminal Differential Pressure (see 5.1.1.3). Measure and record the filter assembly differential pressure at the beginning of each particle count throughout the test. Continuous differential pressure measurement using a differential pressure transducer is recommended.

NOTE: All flow rates must be equal to values listed in Table 4, and maintained within the accuracy listed. If online particle counters require dilution flow, care should be taken to assure that flow does not exceed the coincidence limit of the counters as determined by ISO 11171. It is recommended that test sample flow rate and dilution flow rate ratio be controlled and recorded to calculate the exact amount of test fluid that has passed through the sensor for each particle count. A minimum counting volume of 10 mL is recommended to obtain statistically significant numbers.

5.1.1.9 When the Terminal Differential Pressure has been reached, extract a bottle sample for gravimetric analysis from the upstream sample point, record the final test time, stop the injection system flow, and stop the Main Reservoir flow.

NOTE: If the calculated Terminal Differential Pressure is not reached within 1 h from start of test, verify that tests conditions (e.g., flow, temperature, etc.) are constant. Correct as required. If test conditions are constant, continue for an additional hour or less if the calculated Terminal Differential Pressure is reached.

5.1.1.10 Measure and record the final main reservoir volume. Obtain a bottle sample from the injection system and label as "Final Injection System Gravimetric Sample."

5.1.2 Pulsed Flow Efficiency Test

5.1.2.1 Preliminary Test Preparation

Use a data sheet similar to that illustrated on Figure 5 "Intake Filter Assembly Test Report – Pulsed Flow Test." Complete all pertinent blocks and record all test results on this form.

5.1.2.2 Install an empty housing (no filter element) and circulate test fluid through the main reservoir and test circuit to purge all air. Adjust test parameters to the conditions listed in Table 5A "Pulsed Flow Efficiency Test Parameters." Adjust the pulse envelope to the appropriate conditions described in Table 5B "Pulse Envelope Characteristics" and in Figures 7A and 7B "Typical Pulsed Flow Profiles." When system temperature has reached 38 °C (kinematic viscosity of 15 mm^2/s), circulate for 15 min and establish system cleanliness by using the upstream and downstream particle counters. Verify that the initial cleanliness level is within 1% of the required level. (See Table 2, "Test Condition Values" for specification of level, and Figure 5, "Intake Filter Assembly Test Report – Pulsed Flow Test" for where data is to be recorded).

TABLE 5A - PULSED FLOW EFFICIENCY TEST PARAMETERS

Terminal Diff Press	Test Fluid	Test Temp	Filter Size (Media area – cm^2)	Test Condition (Concentration – See Table 2)	Recommended Contaminant
66 kPa	MIL H 5606-G	38 °C	Up to 250 cm^2	1	See 4.3.1.1
66 kPa	MIL H 5606-G	38 °C	250-500 cm^2	1	"Silica Grains"
66 kPa	MIL H 5606-G	38 °C	500-1000 cm^2	2	and
66 kPa	MIL H 5606-G	38 °C	1000 cm^2 and larger	2	Tables 2, 3A, and 3B

TABLE 5B - PULSE ENVELOPE CHARACTERISTICS

Pulsed Flow Amplitude	Flow rate Steady State	Pulse Ramp (Time to reach 1st time constant)	Duration of Pulse	Cycle Rate
20 L/min	10 L/min	50 ms (±10%)	30 ms (±10%)	1/min
30 L/min	20 L/min	50 ms (±10%)	30 ms (±10%)	1/min
40 L/min	20 L/min	50 ms (±10%)	30 ms (±10%)	1/min
50 L/min	20 L/min	50 ms (±10%)	30 ms (±10%)	1/min