



SURFACE VEHICLE RECOMMENDED PRACTICE

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Brake Hydraulic Component Flow Rate Measurement for High Differential Pressure (>5 bar)

RATIONALE

This recommended practice is intended to provide a standard method, test set up, and test conditions for measuring flow characteristics of brake fluid through brake components in a hydraulic brake circuit, in a high pressure differential flow regime. It maps flow rates through the test specimens, relative to the pressure differential across the test specimen. Data generated in accordance to this standard are intended to be useful towards hydraulic brake response time modeling, towards specifying flow characteristics in brake components to meet desired hydraulic system response characteristics, and diagnosing the contribution of individual hydraulic components to system level response behavior.

FOREWORD

This section details some key points used by the founding task force to set the parameters in this recommended practice:

- Every effort was made to give the user flexibility to define the test specimen (as a component or subsystem comprised of multiple components) according to the measurement needs, but provide enough structure to ensure repeatable measurements from lab to lab. It is critical that a clear definition of the test specimen be determined before the test and documented with the test results.
- Two test classifications are defined, to fit with two commonly occurring needs for flow data, but with different priorities. The first classification seeks to establish uniform test conditions from lab to lab, so that components may be validated to a specification for flow characteristics. The second classification seeks to establish the most realistic in-vehicle test set-up, so that flow data may be generated to support system-level modeling activities.
- The task force recognized that the total duration of a flow event of interest will often be very short - sometimes tenths of a second or less, which makes the transient flow behavior during the build-up to peak pressure and the subsequent slow down as pressure levels equalize of interest. In addition, the volume flow rates with large pressure differentials can be quite high, making it difficult to maintain steady-state without suffering changes in fluid properties due to heating or cavitation. Therefore, the task force carefully considered the necessity of reproducing the transient flow (which would be done by forcing fluid into a closed volume with a step input) versus steady flow (which is the method recommended). By measuring flow through a common set of antilock brake hydraulic control units using both methods, and observing which method produced closer correlation of a brake system model to in-vehicle measured pressure response times, it was determined that the steady flow method produced closer correlation and more repeatable results. Generally, the steady flow method produced lower flow coefficients than the transient method.

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1. SCOPE

This recommended practice provides a method, test set-up, and test conditions for brake hydraulic component flow rate measurement for high differential pressure (>5 bar) flow conditions. It is intended for hydraulic brake components which affect the brake fluid flow characteristics in a hydraulic brake circuit, that are part of a circuit for which the flow characteristics are important to system operation, and that are exposed to high operating pressure differentials (in the 5 to 100 bar range). Typical applications may include measurement of flow through chassis controls valve bodies, orifices in the brake system such as in flow bolts, junction blocks, and master cylinders, and through brake pipe configurations.

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 version of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2994 Brake Hydraulic Component Low Pressure Flow Rate Measurement

3. TEST CLASSIFICATIONS

Two different test classifications are defined, each related to a different purpose for the testing. The classifications are listed below:

1. (Classification 1 - Component Validation) Flow rate measurement for comparison to specification, and for comparing one component design to another.
 - a. Brake Fluid - use standard reference fluid RM6606. Test fluid properties are to be measured before test (viscosity, density, and water content). An alternate fluid may be used if agreed to by all stakeholders in the test result.
 - b. Plumbing and test fixturing not part of test specimen - specified in sufficient detail to allow re-creation of test conditions.
2. (Classification 2 - Model Input Generation) Flow rate measurement to characterize flow through a component for modeling and performance diagnostics.
 - a. Brake Fluid - Design intent fluid, test under design intent conditions.
 - b. Test specimen will typically be an entire subsystem (e.g., connection pipes to ESC unit, ESC unit itself, and piping to calipers).

4. HIGH PRESSURE DIFFERENTIAL TEST PROCEDURE

4.1 Test Apparatus

Please refer to Figure A1 for a diagram of the test set-up and apparatus. Recommended specifications for some equipment may be found in Appendix A (based on equipment used in the development of this recommended practice).

4.1.1 Test Specimen

The object of the test may be a single component, such as the hydraulic control unit (HCU) of a slip control system, or it may be a set of components in series, such as the HCU in series with downstream piping and pipe connections. If the subject of the test is a single component, then any additional plumbing installed to connect the specimen to instrumentation shall be selected to have negligible flow resistance in comparison to the component on test (see 2.1.11). The definition of the test specimen may have an impact on the flow measurements - for example, a different flow vs. pressure drop behavior may be measured on an HCU, pipe, hose, and caliper/flow bolt setup versus measurement of the HCU by itself. It is important that what is considered the test specimen be well defined in the test documentation.

4.1.2 Pressure Source

A hydraulic pressure source sized to maintain the desired peak pressure differential across the test specimens at the corresponding peak flow rate expected is required. A pump capable of delivering 100 cc/s flow with a pressure head of 10000 kPa will be able to cover many automotive hydraulic component flow demands. The pump should be capable of holding a target pressure with an accuracy of $\pm 2\%$, and pressure pulses from the pump should also be less than 2% of the pressure target. An electrically driven, swashplate style pump (swashplate controls system pressure) with an electronic feedback-controlled servo valve (to control pressure upstream of the test specimen) has been found to be suitable for these measurements.

4.1.3 Environmental Enclosure

The test specimen, the brake fluid supply, and the fluid-carrying portion of the test fixturing shall be enclosed in an environmental chamber capable of maintaining temperatures between -25 and 25 °C. The required accuracy is +0 to -3 °C.

4.1.4 Test Fixturing

The test specimen, plumbing, and fluid reservoir shall be mounted in fixture to securely hold the components in the intended position through the test.

4.1.5 Pressure Transducers

The test rig shall be equipped with electronic pressure transducers for measuring the hydraulic pressure differential across the test specimen (the placement shall exclude the flow meter from the measurement). The minimum required accuracy of the pressure transducer(s) is 0.2% of full scale accuracy. Full scale is recommended to be 1 bar. A minimum of two individual pressure transducers, or a differential pressure transducer, is required.

4.1.6 Flow Meter

The test rig shall be equipped with an electronic flow meter to record brake fluid flow through the test specimen. The flow meter is typically installed in between the test specimen and the differential pressure source. The minimum required accuracy 0.2% of full scale accuracy. The recommended range of the flow meter is 0 to 100 cc/s.

4.1.7 Thermocouples

Thermocouples shall be installed in the test chamber and in the center of the fluid reservoir.

4.1.8 Viscometer (REQUIRED for Component Validation classification, optional for Model Input Generation classification).

The test rig shall be equipped with a viscometer plumbed into the hydraulic circuit downstream of the pressure. The viscometer shall be installed in a manner that allows measurement of the brake fluid viscosity while in test conditions (in the environmental chamber, if applicable) just prior to a flow rate measurement being conducted. It is acceptable to install the viscometer in parallel to the test specimen and to use valves to open and close the flow of fluid to the viscometer.

4.1.9 Junctions and Valves

The use of junctions and valves should be minimized within the hydraulic flow path over which the pressure differential is measured (including the test specimen). Piping and tubing that is not part of the test specimen should be selected to minimize the flow disturbance within the test specimen (this generally means avoiding sudden transitions in pipe size, and keeping junctions and valves as far away from the test specimen as practicable). It is recommended that valves be of the ball or plug type (typically with a 90° turn from open to closed), with a seal design that can withstand temperatures down to -40 °C. This type of valve will minimize the change in flow path cross-sectional area over the valve.

4.1.10 Test Fixture Hydraulic Pipe Diameter

The diameter of the piping in the hydraulic circuit outside of the test specimen can affect the flow measurement in two ways. (1) Fixture piping between the test specimen and either the upstream or the downstream pressure transducer can affect the flow characteristics if not sized correctly, and (2) fixture piping that completes the hydraulic circuit outside of the pressure transducers can contribute to excessive heating of the working fluid (brake fluid) and/or limit the flow rates that can be achieved if not sized adequately. It is recommended that the next larger industry standard size relative to the largest diameter pipe in the test specimen (if applicable) or relative to the largest port size (port size refers to the inner diameter of the flow passage of the port) in the test specimen (if applicable) be selected.

Flow losses in fixture piping will vary approximately according to the equations below:

$$(\text{Eq. 1}) \quad Q = \frac{\pi \cdot D^4}{128 \cdot \nu \cdot \rho \cdot L} \cdot \Delta P \quad \text{or} \quad (\text{Eq. 2}) \quad \Delta P = 128 \cdot Q \cdot \frac{\nu \cdot \rho \cdot L}{\pi \cdot D^4}$$

where:

D = diameter of the pipe (m)

ν = viscosity of the fluid (m²/s)

ρ = density of fluid (kg/m³)

L = length of the pipe in (m)

Q = volumetric flow rate (m³/s)

ΔP = pressure drop over the pipe in (Pa)

Example calculation:

For a section of fixture pipe between the upstream pressure transducer and the inlet port of the test specimen, such as an ABS module with the following parameters (note that the same calculation can be done separately for a section of fixture pipe between the outlet of the test specimen and the downstream pressure transducer):

D = 4.763 mm (0.004763 m) - 3/16-inch outside diameter

ν = 0.000150 m²/s (DOT 3 at -25 °C)

ρ = 1038 kg/m³

L = 10 cm (0.010 m)

Q = 20 cc/s = 0.0002 m³/s

$\Delta P = 128 \cdot 0.00002 \cdot 0.000150 \cdot 1038 \cdot 0.01 / (\pi \cdot 0.004763^4) = 2465 \text{ Pa} = 24.7 \text{ millibar}$