
British Standard

Methods for determining pressure ripple levels generated in hydraulic fluid power systems and components

Part 1. Secondary source methods for pumps

Foreword

This revision of BS 6335 : Part 1 has been prepared under the direction of the Machinery and Components Standards Policy Committee.

The 1983 edition of the standard described procedures for the determination of pressure ripples generated by positive displacement hydraulic pumps by a method which was not suitable for high impedance pumps and which was time consuming, often taking several days to conduct.

Researchers have over the past 6 years been developing two alternative simpler procedures which are highly efficient, taking approximately 30 minutes to conduct. This revision describes these methods and supersedes the 1983 edition which is withdrawn.

Further Parts are planned to deal with other hydraulic fluid power components, such as motors and valves.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whom it has been prepared.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

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Method

0 Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. Positive displacement pumps are components that convert rotary mechanical power into hydraulic fluid power. During the process of converting mechanical power into hydraulic power, flow and pressure fluctuations and structure-borne vibrations are generated.

These fluid-borne and structure-borne vibrations, which are generated primarily by the unsteady flow produced by the pump, are transmitted through the system at levels depending upon the characteristics of the pump and the circuit. Thus, the determination of the pressure ripple generated by a pump is complicated by the interaction between the pump and the circuit. The method adopted to measure the pressure ripple levels of a pump should, therefore, be such as to eliminate this interaction.

The measurement technique described in this Part of this standard isolates the pump flow and/or pressure ripple from the effects of such circuit interactions, by mathematical processing of pressure ripple measurements [1 to 5] *. A figure of merit for the pump is obtained which allows pumps of different types and manufacture to be compared as pressure ripple generators. This will enable the pump designer to evaluate the effect of design modifications on the pressure ripple levels produced by the pump in service. It will also enable the hydraulic system designer to avoid selecting pumps having high pressure ripple levels.

The method is based upon the application of plane wave transmission line theory to the analysis of pressure fluctuations in hydraulic systems [6]. By evaluating the impedance characteristics of the circuit into which the pump discharges and the impedance of the pump itself, it is possible to isolate the source flow ripple and/or pressure ripple of the pump from the interactions of the circuit. The impedance characteristics of the circuit can be evaluated by analysis of pressure ripple measurements at two or more positions along a pipe, where the pipe is connected to the discharge port of the pump. However, to characterize the impedance of the system completely, it is not sufficient to measure the pressure ripple generated by the pump alone as insufficient information is available for the impedance of the pump to be evaluated. The secondary source method utilizes another source of pressure ripple at the opposite end of the discharge line. The measurement of this pressure ripple enables the pump source impedance to be evaluated. Sufficient information is then available to evaluate the source flow ripple and pressure ripple of the pump.

Because of the complexity of the analysis, data processing is preferably carried out using a digital computer. Suitable software packages are available from two sources (appendix A).

1 Scope

This Part of BS 6335 describes a procedure for the determination of a rating of the source flow ripple, the source impedance and the pressure ripple levels generated by positive displacement hydraulic pumps. These three ratings are obtained as:

- (a) the source flow ripple amplitude in L/s over 10 individual harmonics of pumping frequency;
- (b) the source impedance amplitude in $\text{N}\cdot\text{s}/\text{m}^5$ † and phase in degrees over 10 individual harmonics of pumping frequency;
- (c) the overall rms pressure ripple in $\text{bar}^\ddagger$, corresponding to the pump discharging into a pipe of the same internal diameter as the pump discharge port, with an anechoic termination.

This Part of the standard is applicable to all types of positive displacement pump operating under steady-state conditions, irrespective of size, provided that the pumping frequency is in the range from 50 Hz to 400 Hz.

NOTE. The title of the publication referred to in this standard is given on the inside back cover.

2 Definitions

For the purposes of this standard the following definitions apply.

2.1 source flow ripple. The fluctuating component of flowrate generated within the pump which is independent of the characteristics of the connected circuit.

2.2 flow ripple. The fluctuating component of flowrate in the hydraulic fluid, caused by interaction of the source flow ripple with the system.

2.3 pressure ripple. The fluctuating component of pressure in the hydraulic fluid, caused by interaction of the source flow ripple with the system.

2.4 anechoic pressure ripple. The pressure ripple which would be generated at the pump discharge port when discharging into an infinitely long rigid pipe of the same internal diameter as the pump discharge port.

2.5 impedance. The complex ratio of the pressure ripple to the flow ripple occurring at a given point in a hydraulic system and at a given frequency.

2.6 source impedance. The impedance of a pump at the discharge port.

2.7 harmonic. A sinusoidal component of the pressure ripple or flow ripple occurring at an integral multiple of the pumping frequency. A harmonic may be represented by its amplitude and phase, or alternatively by its real and imaginary components.

* The numbers in square brackets throughout the text refer to the bibliographic references in appendix D.

† $1 \text{ N}\cdot\text{s}/\text{m}^5 = 1 \text{ Pa}\cdot\text{s}/\text{m}^3$.

‡ $1 \text{ bar} = 10^5 \text{ N}/\text{m}^2 = 10^5 \text{ Pa}$.

2.8 pumping frequency. The frequency (in Hz) given by the product of shaft rotational frequency and the number of pumping elements on that shaft.

2.9 shaft rotational frequency. The frequency (in Hz) given by the shaft rotational speed (in r/min) divided by 60.

3 Instrumentation

3.1 Static measurements

The instruments used to measure:

- (a) mean fluid flow;
- (b) mean fluid pressure;
- (c) shaft rotational speed;
- (d) fluid temperature;

shall meet the requirements for 'industrial class' accuracy of measurement, i.e. class C given in appendix B.

3.2 Dynamic measurements

The instruments used to measure pressure ripple shall have the following characteristics:

- (a) resonant frequency ≥ 30 kHz;
- (b) linearity $< \pm 1$ %.

The instruments need not respond to steady state pressure, and it may be advantageous to filter out any steady state signal component using a high pass filter. This filter shall not introduce an additional amplitude or phase error exceeding 1 % or 2 ° respectively at the pumping frequency.

3.3 Frequency analysis of pressure ripple

A suitable instrument shall be used to measure the amplitude and phase of the pressure ripple, for at least ten harmonics of the pumping frequency.

The instrument shall be capable of measuring the pressure ripple from two or three pressure transducers (6.7) such that, for a particular harmonic, the measurements from each transducer are synchronized in time with respect to each other. This may be achieved by sampling the pressure ripple from each pressure transducer simultaneously, or by sampling each pressure transducer separately, but with respect to a trigger signal obtained from a fixed reference on the pump shaft or secondary source drive, as appropriate.

The instrument shall have an accuracy and resolution for harmonic measurements of:

- (a) amplitude within ± 1 %;
- (b) phase within ± 1 °;
- (c) frequency within ± 0.5 %;

over the frequency range from 50 Hz to 4000 Hz.

3.4 General

Compliance with the above tolerances will result in an uncertainty in the overall rms pressure ripple rating of within ± 10 %.

4 Pump installation

4.1 General

The pump shall be installed in an attitude recommended by the manufacturer and mounted in such a manner that the response of the mounting to pump vibration is minimized.

4.2 Drive vibration

The prime mover and associated drive couplings shall not generate torsional vibration in the pump shaft. If necessary, the pump and the driving unit shall be isolated from each other to eliminate vibration generated by the prime mover.

4.3 Reference signal

A means of producing a reference signal relative to the shaft rotation shall be included. The signal shall be an electrical pulse occurring once per revolution with sharply defined rising and falling edges. This signal is used as a measure of the shaft rotational speed, and may be used if necessary to provide a trigger signal and/or phase reference for the pressure ripple analysis instrument.

5 Test conditions

5.1 General

The required operating conditions shall be maintained throughout each test within the limits specified in table 1.

Table 1. Permissible variations in test conditions	
Test parameter	Permissible variation
Mean flow	± 2 %
Mean pressure	± 2 %
Shaft rotational frequency	± 1 %
Temperature	± 2 °C

5.2 Fluid temperature

The temperature of the fluid shall be that measured at the pump inlet.

5.3 Fluid density and viscosity

The density and viscosity of the fluid shall be known to an accuracy within the limits specified in table 2 [7].

Table 2. Required accuracy of fluid property data	
Property	Required accuracy
Density	± 2 %
Viscosity	± 5 %
Isentropic tangent bulk modulus	± 5 %

5.4 Fluid bulk modulus

The isentropic tangent bulk modulus of the fluid shall be known to an accuracy within the limits specified in table 2 [8]. As this is not always feasible, C.4.2 details a method by which the bulk modulus may be evaluated with a sufficiently high accuracy.

6 Test rig

6.1 General

The test rig shall be installed generally as shown in figure 1. The test rig shall include all fluid filters, fluid coolers, reservoirs, loading valves and any ancillary pumps required to meet the pump hydraulic operating conditions. Specific features are described in 6.2 to 6.13.

6.2 Test fluid

The type of test hydraulic fluid and the quality of filtration shall be in accordance with the pump manufacturer's recommendations.

6.3 Pump

The pump shall be installed in the 'as delivered' condition.

6.4 Inlet line

The internal diameter of the inlet line to the pump shall be in accordance with the pump manufacturer's recommendations. To prevent air leaking into the circuit care shall be exercised when assembling the inlet lines. The supply pressure shall be in accordance with the pump manufacturer's recommendations, and if necessary a boost pump shall be used.

6.5 Inlet pressure gauge

The inlet pressure gauge shall be mounted at the same height as the inlet fitting or shall be calibrated for any height difference therefrom.

6.6 Pump discharge port connection

The adaptor connecting the pump discharge port to the discharge pipe shall have an internal diameter which does not differ from the discharge pipe diameter by more than 10 % at any point. Any such variations in internal diameter shall occur over a length not exceeding twice the pipe internal diameter. The adaptor shall be arranged in order to prevent the formation of air pockets in it. The discharge pipe shall be mounted in line with the pump discharge port without any changes in direction.

6.7 Pump discharge line

6.7.1 General. The discharge pipe shall be a uniform, rigid, straight metal pipe. Pressure transducers shall be mounted along its length, as shown in figure 2. The internal diameter of the pipe shall be between 80 % and 120 % of the diameter of the pump discharge port.

The pressure transducers shall be mounted such that their diaphragms are flush with the inner wall of the pipe to within ± 0.5 mm. No valves, pressure gauges or flexible hoses shall be installed between the pump discharge port and point 'A' as shown on figure 1.

Two alternative specifications for the pump discharge line are given, depending on whether the isentropic tangent bulk modulus of the fluid is known within the limits specified in table 2. These alternatives are henceforth known as 'method 1' and 'method 2'. Method 1 is suitable for use in all situations. However, if the isentropic tangent bulk modulus is known within the limits specified in table 2, economies can be made by using method 2.

