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SURFACE VEHICLE RECOMMENDED PRACTICE

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Hydraulic Pump Airborne Noise Bench Test

RATIONALE

Not applicable.

FOREWORD

This document was created to set a standard test method for measurement of airborne noise from hydraulic pumps commonly used in motor vehicle power steering systems.

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1. SCOPE

Communicate the process of accurately measuring sound power levels of positive displacement hydraulic pumps commonly used in ground vehicle steering systems. This recommended practice defines the pump mounting (pulley, belt tension, isolation), operating conditions (fluid, speed, temperature, pressure), room acoustics, instrumentation, noise measurement technique and data acquisition setup to be used. Included are recommendations for test sample size, and format for data presentation/reporting.

1.1 Purpose

Record a common method to perform testing among vehicle manufacturer and pump suppliers.

2. REFERENCES

2.1 Applicable Publications

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 ISO Publication

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

ISO 3745:2003 Acoustics—Determination of sound power levels of noise sources using sound pressure—Precison methods for anechoic and hemi-anechoic rooms

2.1.2 IEC Publication

Available from International Electrotechnical Commission, 3, rue de Verambe, P.O. Box 131, 1211 Geneva 20, Switzerland, Tel: +41-22-919-02-11, www.iec.ch.

IEC 61672-1 Electroacoustics—Sound Level Meters—Part 1: Specifications

IEC 61672-2 Electroacoustics—Sound Level Meters—Part 2: Pattern Evaluation Tests

2.1.3 ANSI Publication

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

ANSI S1.11 Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters

3. DEFINITIONS

4. PROCEDURE

4.1 Introduction

This procedure is based on ISO Specification 3745 with sound power testing and a 19-microphone array. Details on further test parameters to standardize the measurement of hydraulic pump component airborne noise are provided.

4.2 Instrumentation

Multi-channel data acquisition hardware capable of a sampling rate of 48 kHz. This hardware shall meet class 1 accuracy corresponding to IEC 61672 or be equivalent for the application (precision ± 0.7 dB or ± 8%).

A tachometer is used to monitor the speed of the component under test and provides a control signal as well as a trigger for data acquisition in sweep modes. Two thermocouples are utilized to monitor the temperature of the component and fluid. Two static pressure transducers to measure pump outlet and inlet pressure. Two dynamic pressure transducers used in the pump outlet circuit are optional.

Microphone Array: Microphone and array requirements are defined in ISO 3745 sound power standard. The preferred hemispherical array contains 19 microphones at a 1 meter radius over a reflecting plane as defined in Figure 1 and Table 1. A 0.5 meter array is acceptable if the lowest frequency of interest is met according to ISO 3745.

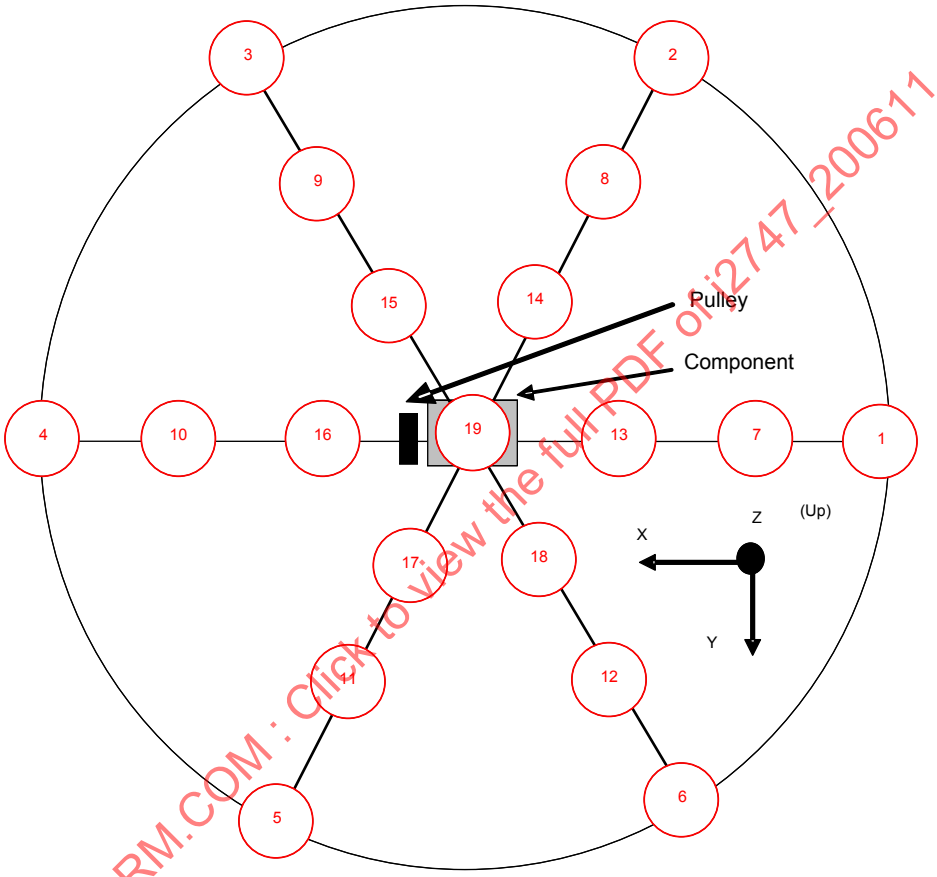

FIGURE 1 - PREFERRED TEST STAND MICROPHONE ARRAY

TABLE 1 - PREFERRED MICROPHONE ARRAY COORDINATES

Microphone Position	X/r	Y/r	Z/r
1	-0.99	0.00	0.15
2	-0.50	-0.86	0.15
3	0.50	-0.86	0.15
4	0.99	0.00	0.15
5	0.50	0.86	0.15
6	-0.50	0.86	0.15
7	-0.89	0.00	0.45
8	-0.45	-0.77	0.45
9	0.45	-0.77	0.45
10	0.89	0.00	0.45
11	0.45	0.77	0.45
12	-0.45	0.77	0.45
13	-0.66	0.00	0.75
14	-0.33	-0.57	0.75
15	0.33	-0.57	0.75
16	0.66	0.00	0.75
17	0.33	0.57	0.75
18	-0.33	0.57	0.75
19	0.00	0.00	1.00

4.3 Equipment and Facilities

4.3.1 Test Facility

The test stand is to be installed in a standard, flat-panel, semi-anechoic quiet room. The room shall have a low-frequency cut-off of 250 Hz, but due to the small size of the test components, measurements may be performed down to 200 Hz. The nominal background level of the room is 25 dB(A) with airborne and seismic noise isolation of 20 dB down from outside noise influences. The ambient temperature should not fluctuate from 21 °C more than ± 3 °C. The airborne noise performance of the test room should be hemi-anechoic with minimum noise “reflections” per standard ISO 3745. Reflective items or anything similar should be removed from the test cell prior to any noise testing.

The back ground level of motor noise without belt must be at least 12 dB below the pump overall noise level for the whole speed range.

If a test facility has a higher cut-off frequency, no data should be reported for the 1/3 octave bands whose center frequencies fall below the cut-off frequency, unless it requested and clearly identified in the test results.

4.3.2 Test Stand

The test stand (Figure 5) is comprised of a fully enclosed electric motor (40 HP typically sufficient for most applications), a silent driveline with journal bearings, and high precision idler pulleys. The motor controller powers the electric motor, and is connected to a control to run sweeps manually or as programmed by the user. A structurally isolated block (1.2 cm (1/2 in) minimum steel or aluminum) serves as a base for the mounting the test component. The base and drive system are mounted on a concrete base with an isolated reflecting plane covering the test stand. A 19-microphone hemispherical array, built according to ISO 3745 specifications, is used for sound power measurements. The microphone array has a 0.5 m or 1 m radius centered on the accessory component and is positioned on a reflecting plane which may be removeable. The microphone array is to be oriented with the rear microphone behind the pump back cover as shown in Figure 1.

4.4 Sample Preparation

4.4.1 Pump Mount Fixture Design Guidelines

The component under test is mounted on the test stand using isolators to duplicate a free-free condition above 300 Hz.

- Rigid body modes in all three mutually perpendicular axis shall be less than 300 Hz.
  - Pump only, does not include belt and hydraulic lines.
- In general, the line of sight between the microphones in the array and the pump body should not be blocked in any way by the fixture base.
  - Exceptions to this rule include; Hydraulic lines, instrumentation cable, belts, pulley and isolators and brackets between pump and isolators.

Fixture Base (portion below isolators, shown in Figure 2)
- Base fixture should be steel or aluminum 1.2 cm (1/2 in) thick or more.
- Base plate and supports should not exceed a vertical height as defined by the lowest microphone position in the array and a line of sight from the microphone to the pump shaft centerline.
- Minimize reflective surface outside the direction of the reflecting plane that can cause acoustic blocking.

Isolators
- No specific brand is recommended.
- No restriction on the number of isolators. A sufficient number should be used to properly support pump under max belt tension used for testing.
- Isolator material – Natural rubber, HNBR, Neoprene or other suitable electrometric material.

Fixtures/brackets between pump and isolators
- Fixture/bracket are used to couple test pump to isolators.
- Fixture/brackets should have low acoustic radiation properties (Stiff and high damping). Fixture/bracket should be machined from solid. Sheet metals of any kind should not be used.
- Should not exceed 20% to total pump mass.
- Fixture/brackets should attach to pump only at existing mount locations.
- Fixture/brackets shall not interconnect pump mounting points around the circumference of the pump to avoid potential to add stiffness to pump housing.
- Mounting points may be interconnected with the same fixture/bracket as long as the mounting points are inline and are on the same mounting boss. (Minimal effect on pump housing stiffness)

Pump Pulley
- Recommend that pulley intended for use with the pump be used.
- No specific pulley is required.

NOTE: The pulley has a significant influence on the airborne noise measurement and should be carefully chosen when testing to compare pump performance.

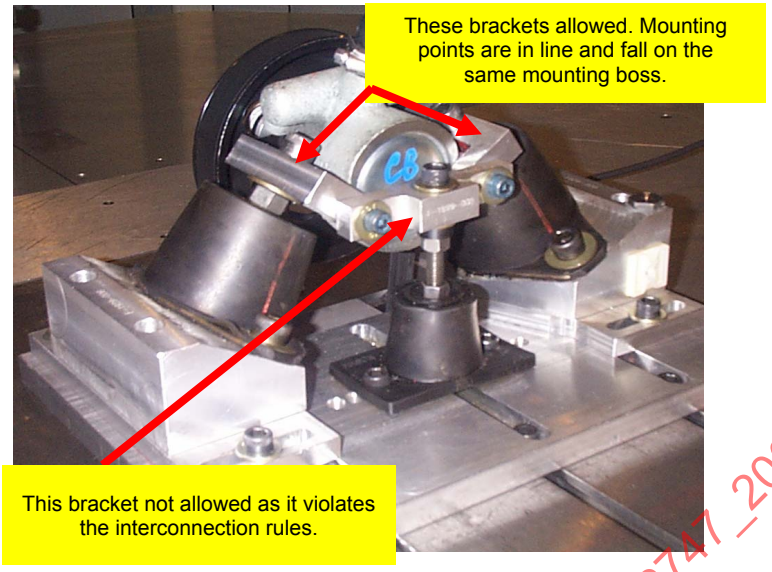

FIGURE 2 - PUMP MOUNTING AND ISOLATOR LOCATION

4.4.2 FRF Measurement for Rigid Body Modes Determination

NOTE: Consistent setup conditions will depend on the component location, belt tension, and choice of isolators. This consistency is a prerequisite to any testing, and repeatable FRF measurements are a validation of this consistency. As a testing requirement, the rigid body modes should always be below 300 Hz.

The Frequency Response Function, FRF, is measured using an accelerometer, appropriate amplifiers, a suitable dynamic signal analyzer and impact hammer. Mount the accelerometer on one of the component's mounts. Impact the component in the axis of measurement and acquire FRF data (acceleration/force) for each direction, from one accelerometer channel at a time a minimum of 3 times. Figure 3 shows an example of a measured FRF on a component and the corresponding rigid body modes below 240 Hz.

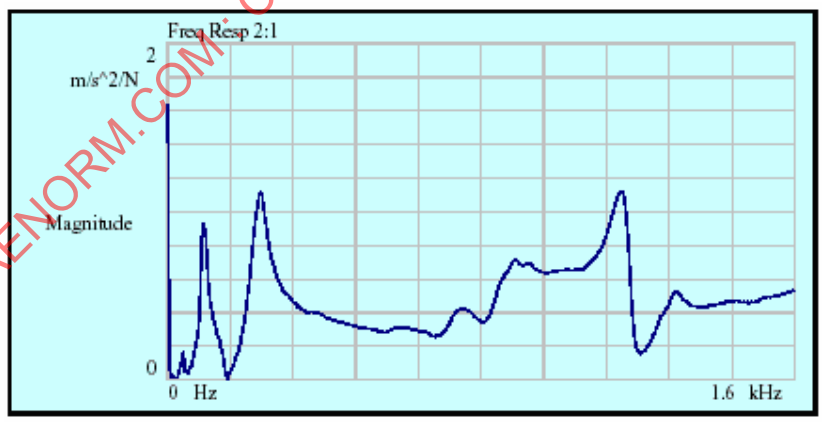

FIGURE 3 - FRF OF PUMP AND THE CORRESPONDING RIGID BODY MODES BELOW 240 HZ

4.4.3 Belt Drive Connection

With the belt attached, position the power steering pump so that the belt does not rub. Use spacers under the isolators when necessary to meet the height requirement or to achieve the required angle and belt tension. Insert closed-cell foam pieces into the opening of the reflective plane to reduce belt noise from beneath the plane. The foam should not make contact with the belt.

4.4.3.1 Tension

The test is to be run with 300 N ± 45 N total hubload. The method to measure belt tension is not specified. Tension may be increased to the amount required to keep required to keep belt from slipping.

4.4.4 Hydraulic System Set-Up (Figure 4)

This system is comprised of a baffled oil reservoir with temperature and aeration control, a discharge hydraulic circuit, and a return line feeds oil through a flow meter and returns the used oil back to the main reservoir.

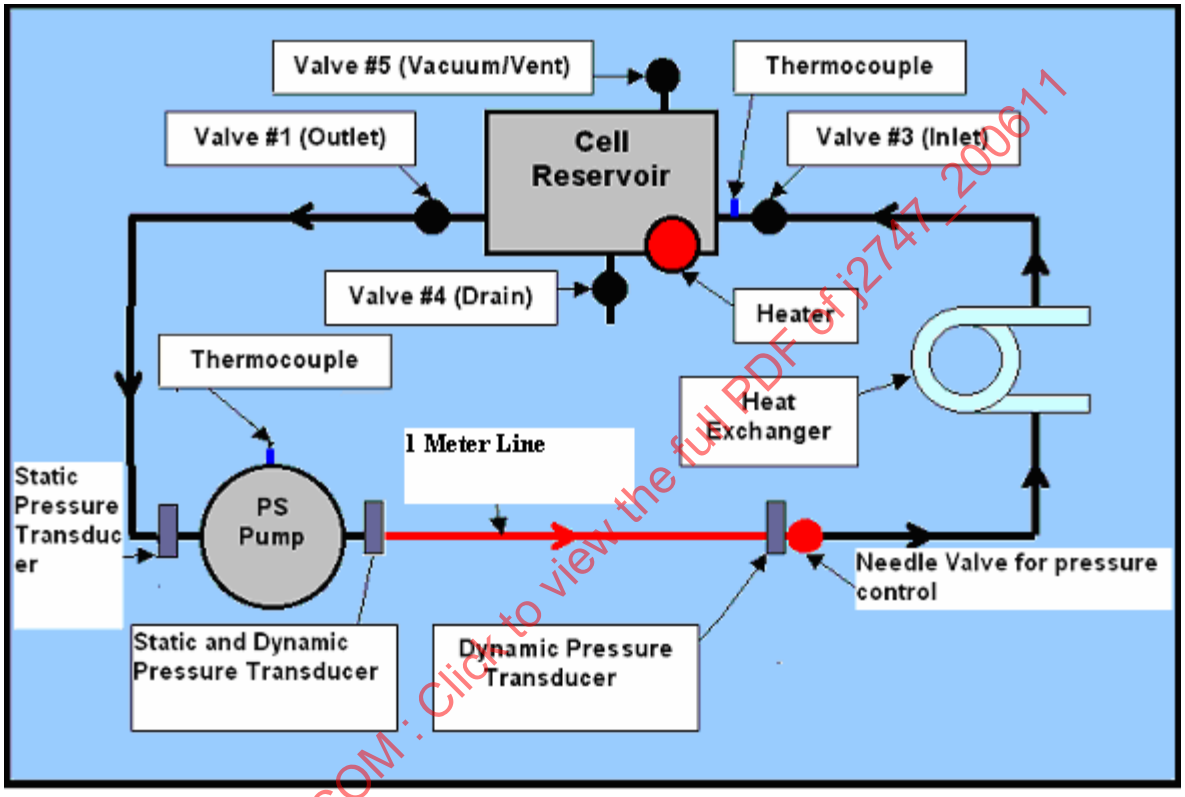

FIGURE 4 - HYDRAULIC CIRCUIT SETUP

4.4.4.1 Reservoir

The hydraulic circuit feeding the intake side of the pump can utilize either a large reservoir (>0.19 m^3 (50 gallon)) or a small reservoir (<0.04 m^3 (10 gallon)). A reservoir volume of 0.02 m^3 (4 gallon) or more is recommended to help maintain control of temperature and aeration. This reservoir maybe connected to a local or “stand by” reservoir. This reservoir is used to keep the conditioned oil in “standby” near the test components to control intake impedance and oil pressure to the test components. Where a small reservoir is used, a de-aeration procedure must be implemented as part of the test set up.

4.4.4.2 Discharge Circuit

The hydraulic circuit on the discharge side of the pump will involve a common steel braided line with a needle valve. The needle valve is to be located outside the microphone array.

4.4.4.3 Hose Specification

0.7 Meter total length between pump discharge and needle valve
Hose shall be constructed as follows.
Smooth bore hose constructed of Carbon Black Static Dissipative Teflon with 304 Stainless Steel Wire Braid Reinforcement
ID = 1.2 cm nominal
Teflon wall thickness = 0.762 mm nominal
20.7 MPa working pressure
0.15 m length of hard tube on both sides of hose section
Temperature range –54 °C to 232 °C

4.4.4.4 Needle Valve Specification

Stainless Steel
Union-Bonnet Needle Valve
0.35 Cv, 0.25 FNPT fitting
w/ Regulating Stem

4.4.4.5 Test Fluid

Dexron or Mercon labled fluid. The test temperature will be specified at 77 °C and ± 7 °C. Record specific fluid used.

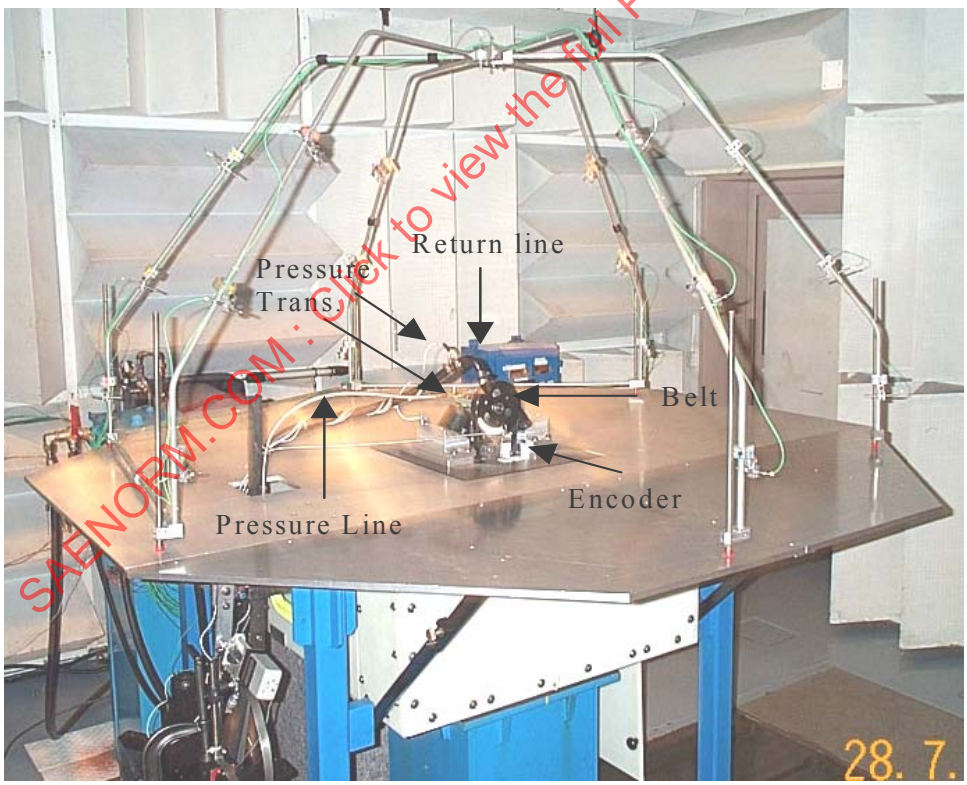

FIGURE 5 - TYPICAL TEST SETUP

4.5 Operation

4.5.1 Test System Warm-Up

Warm up the test system prior to data acquisition by operating the hydraulic power steering pump at 2000 pump rpm at 2.76 MPa for 20 minutes. Verify belt tension is per 4.4.3.1 after warm up.

4.5.2 De-aeration of the System

NOTE: Greater than normal amounts of air trapped in the fluid can result in noise levels that are also greater than normal. To ensure that noise measurements are representative of a normal operating system, a de-aeration procedure should be performed on the system after any component in the system is changed.

Allow the fluid temperature to reach 77 °C. Fully close the discharge pressure adjustment valve. Leave the valve closed for no more than 2 seconds, then re-open it. Repeat this step 3 to 5 times.

Adjust the discharge pressure back to 2.76 MPa at 2000 pump rpm, and listen for air bubbles in the system. Air bubbles will cause an intermittent rattling from the pump, and it is usually very obvious when air is present in the system. Repeat these steps as needed until the air is removed from the system.

4.5.3 Test Conditions

4.5.3.1 Steady State Conditions

TABLE 2 - CONDITIONS FOR STEADY STATE TESTS.

Test	Pump Speed (RPM)	System Pressure (MPa)
1	750	0.83
2	750	5.52
3	1000	0.83
4	1000	5.52
5	1500	5.52
6	2600	5.52

4.5.3.1.1 Data Acquisition

4.5.3.1.1.1 Stabilize Speed and Load Setting

Set hydraulic power steering pump speed and pressure to the test condition.

4.5.3.1.1.2 Verify Test Stand Performance

At each operating speed, confirm the test stand drive system is not generating noise that could corrupt hydraulic power steering pump noise. Extraneous noise can be emitted from the drive belt, bearings, pulley/belt misalignment, or drive motor.

4.5.3.1.1.3 Adjust Input Gain

Adjust the input gain settings of the acquisition system to optimize the dynamic range.

4.5.3.1.1.4 Achieve Operating Temperature

Load the hydraulic power steering pump as required to achieve an initial operating temperature of 77 °C.

4.5.3.1.1.5 Acquire Steady State Noise Data

Acquire 30 seconds of data. Repeat this sequence at each steady state operating speed defined in 4.5.3.1.

Unless otherwise specified, the following test parameter tolerances should be used:

Pump RPM ± 10rpm
Temperature ± 7 °C
Pump Static Pressure ± 0.069 MPa
Pump Suction Pressure ± 3500 Pa

4.5.3.1.2 Data Processing

Process the acquired steady state data to obtain narrowband autopower spectra with these parameters:

- 30 Second Duration
- Sample Rate: 48 kHz minimum
- Frequency Bandwidth: 11.2 kHz
- Window: Hanning, Energy Correction
- Amplitude: Pa^2, RMS
- Averages: 50 linear averages, 50% overlap

4.5.3.1.3 Data Calculations

4.5.3.1.3.1 Conversion to Sound Power

Convert narrowband microphone array data to sound power as defined in ISO 3745 standard (dB linear ref 1 pW).

4.5.3.1.3.2 1/3 Octave Calculation

Synthesize one-third octave bands with center frequencies from 250 Hz to 10 kHz from narrowband sound power data and conforming to filter standards defined in ANSI S1.11 or equivalent standards.

4.5.3.2 Sweep Condition

600 to 8000 pump rpm with a recommended slew rate of 24 rpm/s.

The swept-RPM analysis parameters can be selected at the discretion of the test operator. However, they must meet the following criterion:

$$\frac{\Delta RPM}{60} n \le \left(\frac{f_s}{N}\right)^2 \qquad \text{(Eq. 1)}$$

where

ΔRPM = slew rate in revolutions per minute per second
n = number of the highest order of interest (80th order minimum)
f_s = data sampling rate in Hz
N = block size for the analysis (equal to twice the number of spectral lines)

Additionally, the sampling rate and the block size must be selected such that the frequency resolution Δf given by

$$\Delta f = \frac{f_s}{N} \qquad \text{(Eq. 2)}$$

is less than or equal to 5.86 Hz.

The pump slew rate may not exceed 100 RPM per second.

Higher sampling rates will yield shorter test times at the cost of larger data file sizes. Likewise, a slower sampling rate will yield smaller files sizes at the cost of longer test times.

IMPORTANT: The RPM slew rate must be steady (constant slope, no changes in the rate of change).

4.5.3.2.1 Data Acquisition

4.5.3.2.1.1 Stabilize Speed and Load Setting

The initial pressure shall be established by allowing the system temperature to stabilize at 1000 pump rpm and then setting the system pressure to 0.83 MPa @ 77 °C.

4.5.3.2.1.2 Verify Test Stand Performance

Exercise the system through the entire speed sweep range, 600 to 8000 pump rpm, confirming the test stand drive system is not generating noise that could corrupt hydraulic power steering pump noise. Extraneous noise can be emitted from the drive belt, bearings, pulley/belt misalignment, or drive motor.

4.5.3.2.1.3 Adjust Input Gain

Adjust the input gain settings of the acquisition system as required to optimize the dynamic range over the speed range of the test.

4.5.3.2.1.4 Achieve Operating Temperature

Load the hydraulic power steering pump as required achieving an initial operating temperature of 77 °C.

4.5.3.2.1.5 Acquire Sweep Noise Data

Acquire data while sweeping the hydraulic power steering pump speed from 600 to 8000 pump rpm. Repeat this sequence 3 times.

Unless otherwise specified, the following test parameter tolerances should be used:

Pump RPM ± 10 rpm
Temperature ± 7 °C
Pump Static Pressure ± 0.069 MPa
Pump Suction Pressure ± 3500 Pa

4.5.3.2.2 Data Calculations

4.5.3.2.2.1 Conversion to Sound Power

Convert narrowband microphone array data to sound power as defined in ISO 3745 standard (dB linear ref 1 pW).

4.5.3.2.2.2 Define Fundamental Pump Orders

The number of vanes in the pump is equal to the fundamental order of the pump. Process each sweep test to define the fundamental order and the following seven harmonic orders.

4.5.3.2.2.3 Overall and Order Cut Calculation

Process the narrowband sound power data to provide the following:

- Window: Hanning, Energy Correction
- Amplitude: Pa^2 rms
- Noise Sweeps: 600 to 8000 pump rpm
- 50 pump rpm increments (optional)
- Band Limited Overall Level 250 Hz to 11.2 kHz
- Sweep Noise Order Cuts: Cut the fundamental order and the following seven harmonics with a fixed 16 Hz frequency bandwidth.

The data may be reported in discrete, common RPM steps (e.g. every 50 RPM) over the sweep range at the discretion of the operator, provided the RPM increment size meets the following criterion:

$$RPM_{step} \geq \Delta t \Delta RPM \quad \text{(Eq. 3)}$$

where

Δt is the block length for the data analysis

5. OUTPUT OF TEST

See Appendix for suggested output of test.

6. NOTES

6.1 Key Words

Power steering, pump noise, airborne noise, FEAD noise, whine.

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