SAE International™

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2521

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(R) Disc and Drum Brake Dynamometer Squeal Noise Matrix

Foreword

A European working group that includes car manufacturers, braking system suppliers and friction material companies, developed a dynamometer test procedure known as AK Noise. This procedure follows the lines of the drag mode test procedures with an extension to include deceleration braking. A common approach in the US is to use deceleration mode procedures emphasizing the replication of vehicle road test.

A global squeal matrix has been developed that combines drag mode and deceleration mode tests to meet the strong need for a global standardization of squeal noise dynamometer tests. This procedure was first presented to the SAE working group in February 1999.

Based on the AK drag, deceleration, and friction characterization modules, the matrix with optional Cold Temperature Noise sections and optional Noise after Fade and Recovery sections contains 31 sections with 2321 brake applications total. This procedure owes much to the previous development of the AK procedures. This prior work is gratefully acknowledged.

The latest refinement of this recommended practice incorporates a specifically designed segment, Part B, for the evaluation of drum brake noise. A new optional low temperature section has also been added to the disc brake section to better account for cold brake squeal. The noise data from these sections are intented to represent the squeals generated under low temperature operating conditions

Drum brakes are known to require longer bedding before establishing stable performance properties that are typical of customer perception. Drum brakes also typically provide less torque output than a disc brake at the same pressure. That leads to lower heat generation load. For the above reasons as well as others a noise matrix adaptation for drum brakes has been introduced. The drum brake noise matrix uses a bedding block, a noise search block, then a second more intensive bedding block, followed by a second noise search block, and a final noise search block. Options for heavy duty drum brake and cold noise testing are not included as drum brake variations make it impractical to have a single standard.

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1. Scope

The SAEJ2521 procedure is applicable to high frequency squeal type noise occurrences for passenger car and light truck type vehicles that are used under conventional operating conditions. The procedure incorporates high temperature and low temperature test matrices, but does not fully account for the effects of the environment on brake squeal. Much research is currently underway in this area and can potentially be incorporated in future revisions.

SAEJ2521 procedure is applicable to high frequency squeal type noise occurrences for passenger car and light truck type vehicles that are used under conventional operating conditions. For the purposes of this test procedure, squeal is defined as occurring between 900 and 17,000 Hz for disc brake tests utilizing a full suspension corner assembly, between 2000 and 17,000 Hz for disc brakes not utilizing a full suspension corner assembly and between 500 and 17,000 Hz for drum brakes.

1.1 Purpose

This recommended test practice is intended to establish a common universally recognized method for performing a series of screening test sequences that identify the propensity of a brake assembly to generate squeal noise under a variety of test conditions. The result is an evaluation of the brake propensity to generate brake noise under a set of defined braking conditions that are believed most relevant to braking system development for automobiles.

A disc brake application matrix and drum brake application matrix are defined to describe the test conditions and steps to investigate the influence of pressure, temperature and velocity on squeal noise behavior. Each matrix is intended to replicate vehicle tests to get a fair comparison for different brake corner components.

1.2 Rationale

This procedure has been revised to address to fundamental limitations of the previous version. Drum brake testing was not dealt with in the previous version. Part B of this revised procedure provides a detailed test specification for the evaluation of drum brake noise. This new section was specifically designed and validated for drum brakes.

Another issue was low temperature squeal of disc brakes. The previous procedure did not address this issue. Since the initial release of the procedure, vehicle manufactures have required suppliers to provide cold noise data using a modified version of SAE J2521. The revised disc brake procedure incorporates a cold section for brake noise analysis that satisfies this requirement and provides a practical evaluation procedure.

2. References

There are no reference publications specified herein.

3. Definitions

To facilitate the application of this SAE Recommended Practice, the following definitions are provided.

3.1 General Definitions

a. GVW — Gross vehicle weight.
   Total maximum allowable weight for the vehicle as indicated by the manufacturer.

b. Initial speed
   Braking speed at which brake application is intiated and measured using a calibrated speed sensor.

3.2 Test Apparatus Definition

a. Operational Requirements:
   1. 60 kW (80.5 hp) or more driving power, as determined by the torque requirements of the brake under test.
   2. Speed range up to 100 km/h (62 mph).
   3. Inertia may be actual flywheels, simulated, or a combination of the two.
   4. Reversible brake rotation capability.
   5. Steady-state motor brake torque capability of at least 1500 N·m (1106 ft-lb).
   6. Brake pressure ramp rate of 100 ± 25 bar/s (1450 ± 362.5 lb/in^2-s)
   7. Maximum brake application pressure of 160 bar (2,320 lb/in^2).

b. Environment Requirements:
   1. Humidity control is optional.
   2. Air conditioning is recommended for ambient temperature control.
   3. Cooling air shall be provided to the brake. Note that the airflow shall be controlled such that it will not be so high as to blow away wear debris or create noise above the background limit of 60 dB(A) above 0.9 kHz.
   4. Allowable cooling air temperature range from –10 to 40 °C (14 to 104 °F).
   5. Allowable humidity range is from 20% to 90% and must be recorded.

c. Inertia:
   1. In the absence of a specified inertia, the following values should be used.
   2. For a brake for a front application, the inertia is calculated to be equivalent to 75% of one-half of the gross vehicle weight.
   3. For a rear application, the inertia is calculated to be equivalent to 25% of one-half of the gross vehicle weight.

d. Fixturing:
   1. It is recommended that the brake be mounted in the test apparatus using the actual vehicle suspension and axle components. The suspension components should be as complete as possible to the connection points with the vehicle structure. All bushings, including those at the structural connection points, should be utilized in the fixturing. However it is recognized that it may not always be possible to use the entire suspension corner. In such cases, an undisturbed knuckle should be used.
   2. The fixture should be loaded to the normal operational conditions of the vehicle corner to insure proper alignments and compliance. The preferred method of loading is to use a single compliant tension element acting vertically, but not restricting vibration in the vehicle longitudinal or lateral directions.
   3. If it is not possible to utilize the full suspension corner, care should be taken to match as closely as possible the actual mounting and operating configurations. In such cases, there may be differences in the measured noise below 2000 Hz, when compared to on-vehicle performance.
   4. The brake fixturing utilized must be reported.

3.3 Measurements

a. Noise Transducer Location (see Figure 1)
   1. 10 cm outboard from wheel hub face along the centerline of the axle.
   2. 50 cm above and perpendicular to the centerline of the axle.

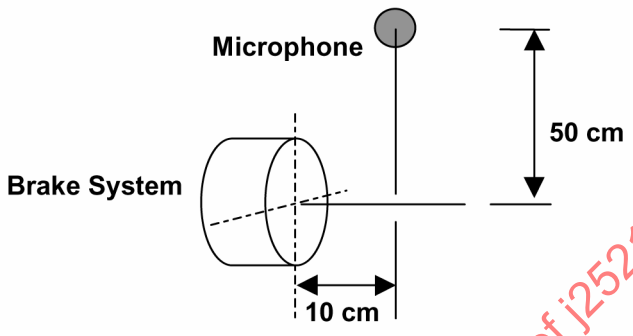

FIGURE 1—MICROPHONE ORIENTATION

b. Noise Measurements
   1. Sound Pressure Level (SPL, dB re 20 μPa) shall be measured in the test chamber throughout the duration of each brake application for all sections.
   2. 60 dB(A) at frequencies above 0.9 kHz is the maximum permissible background noise level within the test chamber.
   3. Brake applications with a Peak Sound Level ≥ 70 dB(A) are determined to exceed the noise data recording peak threshold. The frequency ranges for this threshold are:
      A. 0.9 – 17 kHz for disc brake tests utilizing a full suspension corner assembly.
      B. 2 – 17 kHz for disc brake tests NOT utilizing a full suspension corner assembly.
      C. 0.5 – 17 kHz for drum brake tests.
   4. A sound pressure level threshold of ≥ 70 dB(A) will be used for recording sound.
   5. The recommended transducer for sound measurement is a 0.5” free-field condenser microphone.
   6. A frequency analyzer and/or digital data acquisition system shall be used to acquire the sound measurements. The system must compute and record narrowband sound pressure spectra using the following parameters and capabilities:
      A. 500 - 20 kHz frequency bandwidth with a 25 Hz frequency resolution.
      B. Peak Hold averaging with 50% overlap processing and Hanning windowing applied to the time records.
      C. Anti-aliasing filtering.
      D. A - weighting.
   7. Noise measurement duration is the same as the duration of the brake application for all sections.
   8. Microphone information may be saved as peak hold spectra, time recordings, peak-hold history at fixed intervals, or peak dB(A) and corresponding frequency at fixed intervals.
   9. Accelerometers may be used for validation of noise events.

c. Temperature Measurements
All references to temperature, unless specifically noted, refer to rotor or drum temperature measurements.
1. Disc Brakes:
   A. The recommended method for measuring rotor temperature is using an infrared measurement on the inboard face of the outside diameter of the disc. When using infrared measurements the outside diameter of the rotor should be coated with a material that will provide an emissivity consistent with that required by the infrared measurement system.
   B. As an alternative embedded thermocouples may be used to monitor the rotor temperature. This approach is not the preferred method since embedding the thermocouple may lead to changes in the rotor and its noise performance. The thermocouple shall be on the inboard face of the outside diameter of the disc. It will be set at a depth of 0.5 mm ± 0.1 mm (0.020 in ± 0.004 in) from the outer surface. When high temperature fade tests are done, a thermocouple on the backing plate is recommended to monitor temperature.
2. Drum Brakes:
   A. Temperature is recommended to be measured with a thermocouple embedded in the braking surface of the drum at middle point of the brake shoe rubbing path and set to a depth of 0.5 mm ± 0.1 mm (0.020 in ± 0.004 in). A telemetry system or slip rings will be required in this case. Alternatively, an embedded thermocouple set to a depth of 0.5 mm ± 0.1 mm (0.020 in ± 0.004 in) at the center of the primary braking shoe may be used.
3. Redundant temperature measurements should be made to prevent accidental overheating.

d. Required Measurements
1. Pressure, torque, temperature, and speed should be recorded for each brake application at the same sampling rate ≥ 10Hz.
2. Initial brake temperature — Record rotor or drum temperature for each brake application at the time brake application is initiated. The sampling rate is ≥ 10Hz

3.4 Data Analysis Calculations

a. Effectiveness: Disc Brake - Friction Coefficient (μ):
1. The evaluation of the friction coefficient will only be performed at the prescribed temperature steps. Warm-up brake applications will not be evaluated.
2. The friction coefficient for a disc brake application is an average over the time of the application. The friction coefficient is determined using the follow formulae:

$$\mu = \frac{Md_{Brake}}{2(p - p_{Threshold}) * A_{Piston} * r_{eff} * \eta} \qquad \text{(Eq. 1)}$$

where:

μ = coefficient of friction
Md_{Brake} = instantaneous brake torque, N·m
p = instantaneous pressure, bar
$p_{Threshold}$ = initial pressure threshold, bar
A_{Piston} = piston area, mm2
r_{eff} = effective rotor radius, mm
η = efficiency – assumed to be 100%

3. The initial threshold pressure is 0.5 bar for a disc brake.
4. The effective rotor radius is defined as the radial distance from the horizontal brake centerline to the center of the piston.
5. The Friction Coefficient is averaged by time during the period the pressure or torque is above 90% of the test control level. The evaluation begins when the pressure or torque brake application first attains 90% of the control level. The evaluation ends when the control level is below 90% at the end of the brake apply.

b. Effectiveness: Drum Brake – Brake Effectiveness Factor (BEF):
   1. Brake Effectiveness Factor or Brake Factor for drum brakes is calculated according to the following formula:

$$\text{Brake\_Factor} = \frac{\text{Friction\_Force}}{\text{Actuation\_Force}} \quad \text{(Eq. 2)}$$

$$\text{Brake\_Factor} = \frac{\text{Brake\_Torque}}{\text{Drum\_Braking\_Surface\_Diameter} \times \text{Pressure} \times \text{Wheel\_Cylinder\_Area}} \quad \text{(Eq. 3)}$$

   2. The Brake Factor is averaged by time during the period the pressure or torque is above 90% of the test control level. The measurement begins when the pressure or torque brake application first attains 90% of the control level. The measurement ends when the control level is below 90% at the end of the brake apply.

c. Noise Occurrence, % Absolute:
   1. The percentage of total brake applications with a peak sound level ≥ 70 dB(A).
   2. It is calculated by dividing the number of brake applications with a noise level ≥ 70 dB(A) by the total number of brake applications in the test.
   3. The frequency ranges for this threshold are:
      A. 0.9 – 17 kHz for disc brake tests utilizing a full suspension corner assembly.
      B. 2 – 17 kHz for disc brake tests NOT utilizing a full suspension corner assembly.
      C. 0.5 – 17 kHz for drum brake tests
   4. Summary graphs can be created for sub ranges of pressure, temperature, initial speed and peak sound level.

d. Noise Relative Occurrence:
   1. The number of stops in a single test section with a peak sound level ≥ 70 dB(A) divided by all of the brake applications where the sound level exceeded the 70 dB(A) level – expressed as a percentage.
   2. The frequency ranges for this threshold are:
      A. 0.9 – 17 kHz for disc brake tests utilizing a full suspension corner assembly.
      B. 2 – 17 kHz for disc brake tests NOT utilizing a full suspension corner assembly.
      C. 0.5 – 17 kHz for drum brake tests
   3. These data can be shown as a summary bar graph of all sections.

3.5 Brake Operations

a. Snub Braking Operation (Disc Brakes Only):
   1. Brake snubbing operation from 80 km/h to 30 km/h (see Figure 2) under different braking pressures is performed during the bedding program.
   2. The braking time, t, is a result of the test rig inertia or is adapted to match the desired vehicle configuration.

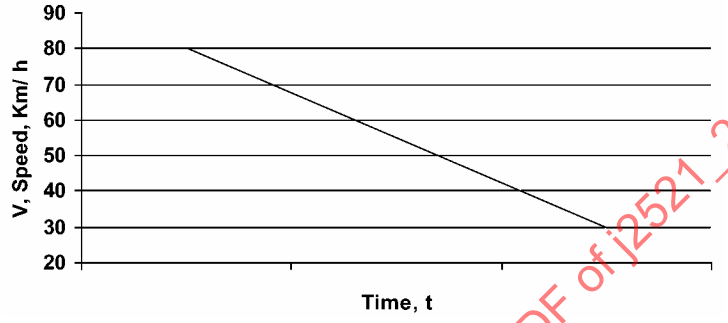

FIGURE 2—BRAKE OPERATIONS

b. Drag Braking Operation (constant speed brake applications):
   1. In order to evaluate brake noises, brake drag operations are required according to the braking pressure ramp shown in Figure 3.
   2. The increase of the brake pressure is 1 bar per second from Pn (normal mean value) -2.5 bar to Pn+2.5 bar at the same speed then decrease (up-ramp at 1 bar/s for 5 seconds then down-ramp at 1 bar/s for 5 seconds). The total braking time shall be 10 seconds.
   3. Before the brake drag operation, warming or cooling operations shall adjust the temperature of the rotor or drum.
   4. The test speeds shall alternate between 3 and 10 km/h for disc, 5 and 10 km/h for drum.
   5. For the special case of 0 bar pressure, the pressure operating range should be from 0 bar to 2.5 bar and back to 0 bar as shown in Figure 4.

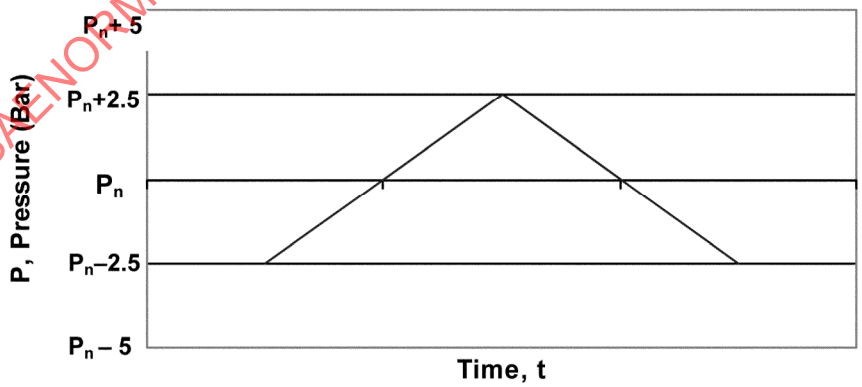

FIGURE 3—BRAKING PRESSURE RAMP

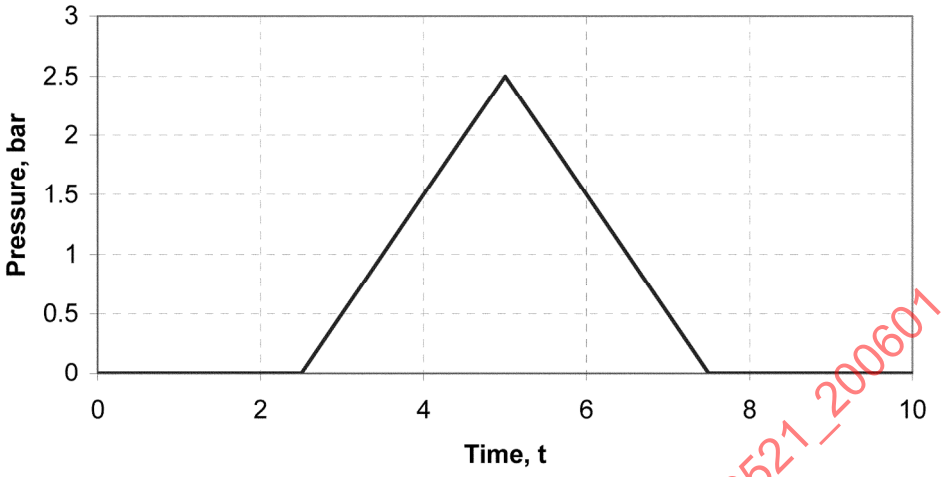

FIGURE 4—BRAKING PRESSURE RAMP FOR 0 BAR CASE

c. Deceleration Braking Operations:
   1. Brake applications are performed from the highest speed required in the test matrix to a speed lower than 0.5 km/h as shown in Figure 5 with defined normal pressure.
   2. The braking time is either obtained from the test rig inertia or adapted to match the desired vehicle configuration.
   3. The rate of pressure increase during these cycles must be at least of 250 ±50 bar/s (3,625 ± 725 lb/in^2-s).

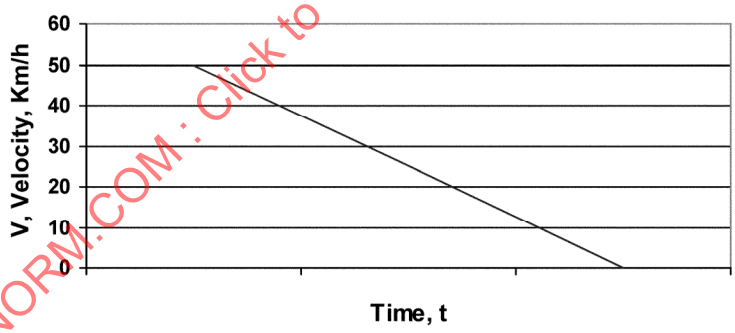

FIGURE 5—STOP OPERATION

d. Warm-up Operation:
   1. If the temperature decreases below the initial temperature of the next braking condition, brake warm up is required by a drag brake operation until the initial braking temperature is reached.
   2. Disc Brakes: Drag operation speed = 50 km/h, braking pressure = 20 bar.
   3. Drum Brakes: Drag operation speed ≤ 50 km/h, braking pressure ≤ 30 bar.

e. Intermediate Conditioning and Warm-up:
   1. This operation is designed to provide conditioning and warm-up between the end of the drag cycle and the beginning of the forward-backward section.
   2. A series of stops are executed to warm-up the brake to 150°C while also providing conditioning.

f. Cooling:
   1. Cooling-down operation to achieve Initial Brake Temperature is preferably achieved at a speed less than 20 km/h.

g. Cold Temperature Sections (Disc Brakes Only):
   1. This section is designed to screen the brake for noise propensity at low temperatures.
   2. For the initial 0°C condition the brake systems should be soaked at 0°C for a period of at least 45 minutes. The preferred temperature measurement location is on the rotor as described in the Temperature Measurements section.
   3. Cold Matrix B consists of a ramped pressure apply with an apply rate of 20 bar/s and held at 20 bar for 3 seconds.

h. Temperature Fade Operation (Disc Brakes Only)
   1. The Temperature Fade cycle is initial brake apply temperature and constant torque level controlled. The brake torque is calculated from the weight of the car, the brake force distribution, the dynamic tire radius, and the rate of deceleration. The torque is computed to provide a 0.4 g deceleration.
   2. Starting temperatures for fade operation brake applications are shown in Table 1 and Table 2:

TABLE 1—FRONT DISC FADE INITIAL TEMPERATURES

Application Number	Temperature, °C	Application Number	Temperature, °C
1	100	9	465
2	215	10	483
3	283	11	498
4	330	12	513
5	367	13	526
6	398	14	539
7	423	15	550
8	446		

TABLE 2—REAR DISC FADE INITIAL TEMPERATURES

Application Number	Temperature, °C	Application Number	Temperature, °C
1	100	9	303
2	164	10	313
3	201	11	321
4	228	12	329
5	248	13	337
6	265	14	344
7	280	15	350
8	292		

   3. If the brake initial temperature steps from the tables above are not obtained, perform a drag apply at 80 km/h with a torque equivalent to 0.2 g deceleration to warm-up the brake. The warm-up procedure should be applied for no more than 20 seconds. Noise evaluation will only be carried out on the stops where the initial temperature matches those as appropriate in Table 1 or Table 2.

4. The temperatures in Table 1 and Table 2 have been determined using a logarithmic formula:

$$T_{AN} = (T_{A15} - T_{A1}) \cdot LN(N) / LN(15) + T_{A1} \quad \text{(Eq. 4)}$$

where:

T_{AN} = initial temperature for a particular application number (AN), °C
T_{A15} = initial temperature for the fifteenth brake application, °C
T_{A1} = initial temperature for the first brake application, °C
N = application number (1-15)

4. Part A: Disc Brake Test Matrix

4.1 Summary of Test Matrix Sections

a. Noise Evaluation Sections
Section 1 to Section 18, 1430 Noise Analysis Brake Applications Total

b. Optional Sections – Cold Temperature Noise
Section 19 to Section 24, 404 Noise Analysis Brake Applications Total

c. Optional Sections – Noise After Fade and Recovery
Section 25 to Section 31, 487 Noise Analysis Brake Applications Total

d. Total brake applications with optional sections = 2321
These are brake applications with noise data acquisition and do not include warm-up applications.

4.2 Noise Evaluation Sections

SECTION 1 BREAK-IN **30 APPLIES**

Cycle	# Of Applications	Initial Speed	Final Speed	Pressure (bar)	Initial Temp.
1.1	30	80 km/h	30 km/h	30	100 °C

SECTION 2 BEDDING **32 APPLIES**

Cycle	# Of Applications	Initial Speed	Final Speed	Pressure (bar)	Initial Temp.
2.1	32	80 km/h	30 km/h	15, 30, 15, 18, 22, 38, 15, 26, 18, 34, 15, 26, 15, 22, 30, 46, 26, 51, 22, 18, 42, 15, 18, 46, 26, 15, 34, 22, 18, 30, 18, 38	100 °C

OPTIONAL SECTION 3 FRICTION CHARACTERISTIC VALUE AFTER BREAK-IN **6 APPLIES**

Cycle	# Of Applications	Initial Speed	Final Speed	Pressure (bar)	Initial Temp.
3.1	6	80 km/h	30 km/h	30	100 °C

SECTION 4 DRAG MODULE **266 APPLIES**

Cycle	# Of Applications	Initial Speed	Pressure (bar)	Initial Temp.
4.1	14	3 & 10 km/h (Alternate)	0, 30, 5, 25, 10, 20, 15	50 °C
4.2	same	same	same	75 °C
4.3	same	same	same	100 °C
4.4	same	same	same	125 °C
4.5	same	same	same	150 °C
4.6	same	same	same	175 °C
4.7	same	same	same	200 °C
4.8	same	same	same	225 °C
4.9	same	same	same	250 °C
4.10	same	same	same	300 °C
4.11	same	same	same	250 °C
4.12	same	same	same	225 °C
4.13	same	same	same	200 °C
4.14	same	same	same	175 °C
4.15	same	same	same	150 °C
4.16	same	same	same	125 °C
4.17	same	same	same	100 °C
4.18	same	same	same	75 °C
4.19	same	same	same	50 °C

* Run 3 & 10 km/h brake applications for each pressure then proceed to the next pressure level.

SECTION 5 INTERMEDIATE CONDITIONING AND WARM-UP MODULE **24 APPLIES**

Cycle	# of Applications	Initial Speed	Final Speed	Pressure (bar)	Initial Temp.
5.1	12	50 km/h	0 km/h	30, 5, 25, 10, 20, 15	100 °C
5.2	same	same	same	same	150 °C

* Run 2 stops for each pressure. For example, 30 bar at 100 °C for 2 stops. Then run 5 bar at 100 °C for 2 stops. Repeat this for the 150 °C cycle.

SECTION 6 BACKWARD/FORWARD **50 APPLIES**

Cycle	# of Applications	Initial Speed	Pressure (bar)	Initial Temp.
6.1	10	-3, 3 km/h (Alternate)	0, 20, 5, 15, 10	150 °C
6.2	same	same	same	125 °C
6.3	same	same	same	100 °C
6.4	same	same	same	75 °C
6.5	same	same	same	50 °C

* Run -3 & 3 km/h brake applications for each pressure then proceed to the next pressure level.

SECTION 7 DECELERATION MODULE 108 APPLIES

Cycle	# of Applications	Initial Speed	Final Speed	Pressure (bar)	Initial Temp.
7.1	12	50 km/h	0 km/h	30, 5, 25, 10, 20, 15	50 °C
7.2	same	same	same	same	100 °C
7.3	same	same	same	same	150 °C
7.4	same	same	same	same	200 °C
7.5	same	same	same	same	250 °C
7.6	same	same	same	same	200 °C
7.7	same	same	same	same	150 °C
7.8	same	same	same	same	100 °C
7.9	same	same	same	same	50 °C

* Run 2 stops for each pressure. For example, 30 bar at 50 °C for 2 stops. Then run 5 bar at 50 °C for 2 stops. Continue this for the remaining pressures. Do this for all 9 cycles.

SECTION 8 FRICTION CHARACTERISTIC VALUE AFTER BREAK-IN 6 APPLIES

Repeat Section 3 above

SECTION 9 DRAG MODULE 266 APPLIES

Repeat Section 4 above

SECTION 10 INTERMEDIATE CONDITIONING AND WARM-UP MODULE 24 APPLIES

Repeat Section 5 above

SECTION 11 BACKWARD/FORWARD 50 APPLIES

Repeat Section 6 above

SECTION 12 DECELERATION MODULE 108 APPLIES

Repeat Section 7 above

SECTION 13 FRICTION CHARACTERISTIC VALUE AFTER BREAK-IN 6 APPLIES

Repeat Section 3 above

SECTION 14 DRAG MODULE 266 APPLIES

Repeat Section 4 above

SECTION 15 INTERMEDIATE CONDITIONING AND WARM-UP MODULE 24 APPLIES

Repeat Section 5 above

SECTION 16 BACKWARD/FORWARD 50 APPLIES

Repeat Section 6 above

SECTION 17 DECELERATION MODULE 108 APPLIES

Repeat Section 7 above

SECTION 18 FRICTION CHARACTERISTIC VALUE AFTER BREAK-IN 6 APPLIES

Repeat Section 3 above

4.3 Optional Sections – Cold Temperature Noise

Sections 19-24 are optional. The noise data from these sections will represent the squeals generated under low temperature operating conditions. For the initial 0 °C condition the brake systems should be soaked a 0 °C for a period of at least 45 minutes. The pressure ramps as descrived in 3.5b Drag Brake Operation shall be applied in Sections 19, 21, 22, and 24.

SECTION 19 COLD MATRIX A **77 APPLIES**

Cycle	# of Applications	Initial Speed	Pressure (bar)	Initial Temp.
19.1	7	5 km/h constant	0, 12, 3, 10, 5, 8, 7	0 °C
19.2	same	same	same	10 °C
19.3	same	same	same	20 °C
19.4	same	same	same	30 °C
19.5	same	same	same	40 °C
19.6	same	same	same	50 °C
19.7	same	same	same	40 °C
19.8	same	same	same	30 °C
19.9	same	same	same	20 °C
19.10	same	same	same	10 °C
19.11	same	same	same	0 °C

SECTION 20 COLD MATRIX B **55 APPLIES**

Cycle	# Of Applications	Initial Speed	Pressure (bar)	Initial Temp.
20.1	5	30 km/h constant	All Stops: Ramp apply to 20 bar at 20 bar/sec, 3 sec total duration	0 °C
20.2	same	same		10 °C
20.3	same	same		20 °C
20.4	same	same		30 °C
20.5	same	same	same	40 °C
20.6	same	same	same	50 °C
20.7	same	same	same	40 °C
20.8	same	same	same	30 °C
20.9	same	same	same	20 °C
20.10	same	same	same	10 °C
20.11	same	same	same	0 °C

SECTION 21 COLD BACKWARD/FORWARD **70 APPLIES**

Cycle	# Of Applications	Initial Speed	Pressure (bar)	Initial Temp.
21.1	10	-5, 5 km/h (Alternate)	0, 12, 3, 10, 5, 8, 7	0 °C
21.2	same	same	same	5 °C
21.3	same	same	same	10 °C
21.4	same	same	same	20 °C
21.5	same	same	same	30 °C
21.6	same	same	same	40 °C
21.7	same	same	same	50 °C

* Run -5 & 5 km/h brake applications for each pressure then proceed to the next pressure level.

SECTION 22	COLD MATRIX A	77 APPLIES
Repeat Section 19 above		

SECTION 23	COLD MATRIX B	55 APPLIES
Repeat Section 20 above		

SECTION 24	COLD BACKWARD/FORWARD	70 APPLIES
Repeat Section 21 above		

4.4 Optional Sections – Noise After Fade and Recovery

Sections 25-31 are optional. The noise data from these sections will represent the squeals generated after severe fade and recovery.

SECTION 25 TEMPERATURE FADE MODULE — **15 APPLIES**

Cycle	# of Applications	Initial Speed	Final Speed	Deceleration	Maximum Pressure	Initial Temp. (°C)
25.1	15	100 km/h	0 km/h	0.4 g	160 bar	100, 215, 283, 330, 367, 398, 423, 446, 465, 483, 498, 513, 526, 539, 550

SECTION 26 RECOVERY — **18 APPLIES**

Cycle	# of Applications	Initial Speed	Final Speed	Pressure (bar)	Initial Temp.
26.1	18	80 km/h	30 km/h	30	100 °C

SECTION 27	DRAG MODULE	266 APPLIES
Repeat Section 4 above		

SECTION 28	INTERMEDIATE CONDITIONING AND WARM-UP MODULE	24 APPLIES
Repeat Section 5 above		

SECTION 29	BACKWARD/FORWARD	50 APPLIES
Repeat Section 6 above		

SECTION 30	DECELERATION MODULE	108 APPLIES
Repeat Section 7 above		

SECTION 31	FRICTION CHARACTERISTIC VALUE AFTER BREAK-IN	6 APPLIES
Repeat Section 3 above		

5. Part B: Drum Brake Test Matrix

SECTION 1 FIRST BEDDING

Section	Applications Total	Vi (km/h)	Vf (km/h)	Decel (g)	IBT (°C)	Pressure (bar)
1.1	25	80	0	0.3	100 or 1.6 km	
1.2	25	80	0	0.1	same	
1.3	25	80	0	0.25	same	
1.4	25	80	0	0.2	same	
Repeat 1.1-1.4	100	80	0		same	
1.5	2	40 (rev)	0	0.3	same	

SECTION 2 FRICTION EVALUATION – AFTER FIRST BEDDING

Section	Applications Total	Vi (km/h)	Vf (km/h)	Decel (g)	IBT (°C)	Pressure (bar)
2.1	6	80	0		100	30

SECTION 3 DRAG NOISE SECTION

Section	Applications Total	Vi (km/h)	Vf (km/h)	Decel (g)	IBT (°C)	Pressure, (bar)
3.1	12	5,10	5,10		75	30,5,25,10,20,15 ±2.5 ramp
3.2	Same	same	same		100	same
3.3	Same	same	same		125	same
3.4	Same	same	same		150	same
3.5	Same	same	same		175	same
3.6	Same	same	same		200	same
3.7	Same	same	same		175	same
3.8	Same	same	same		150	same
3.9	Same	same	same		125	same
3.10	same	same	same		100	same
3.11	same	same	same		75	Same

* Run 5 & 10 km/h brake applications for each pressure then proceed to the next pressure level.

SECTION 4 CONDITIONING STOPS SECTION

Section	Applications Total	Vi (km/h)	Vf (km/h)	Decel (g)	IBT (°C)	Pressure (bar)
4.1	10	50	0		100	30, 10, 25, 15, 20
4.2	10	50	0		150	Same

* Run 2 stops for each pressure. For example, 30 bar at 100°C for 2 stops. Then run 10 bar at 100°C for 2 stops.

SECTION 5 BACKWARD / FORWARD DRAG

Section	Applications Total	Vi (km/h)	Vf (km/h)	Decel (g)	IBT (°C)	Pressure (bar)
5.1	8	-5 / 5	-5 / 5		150	20,5,15,10 ±2.5 ramp
5.2	same	same	same		125	Same
5.3	same	same	same		100	Same
5.4	same	same	same		75	Same
5.5	same	same	same		50	Same

* Run -5 & 5 km/h brake applications for each pressure then proceed to the next pressure level.

SECTION 6 DECEL NOISE STOPS SECTION

Section	Applications Total	Vi (km/h)	Vf (km/h)	Decel (g)	IBT (°C)	Pressure (bar)
6.1	12	50	0		75	30,7,25,10,20,15
6.2	same	same	same		100	Same
6.3	same	same	same		125	Same
6.4	same	same	same		150	Same
6.5	same	same	same		175	Same
6.6	same	same	same		200	Same
6.7	same	same	same		175	Same
6.8	same	same	same		150	Same
6.9	same	same	same		125	Same
6.10	same	same	same		100	Same
6.11	same	same	same		75	Same

* Run 2 stops for each pressure. For example, 30 bar at 75 °C for 2 stops. Then run 7 bar at 75 °C for 2 stops.

SECTION 7 SECOND BEDDING

Section	Applications Total	Vi (km/h)	Vf (km/h)	Decel (g)	IBT (°C)
7.1	25	80	0	0.3	100 or 1.6 km
7.2	25	80	0	0.1	100 or 1.6 km
7.3	25	80	0	0.25	100 or 1.6 km
7.4	25	80	0	0.2	100 or 1.6 km
7.5 (Repeat 7.1-7.4)	100	80	0		100 or 1.6 km
7.6	2	40 (rev)	0	0.3	100 or 1.6 km
Repeat 7.1-7.6	102		0		150
Repeat 7.1-7.6	102		0		200
Repeat 7.1-7.6	102		0		150
Repeat 7.1-7.6	102		0		100
Repeat 7.1-7.5	100		0		125

2ND NOISE SEARCH BLOCK

SECTION 8 FRICTION EVALUATION **6 APPLIES**

Repeat Section 2 above

SECTION 9 DRAG NOISE SECTION **132 APPLIES**

Repeat Section 3 above

SECTION 10 CONDITIONING STOPS SECTION **20 APPLIES**

Repeat Section 4 above

SECTION 11 BACKWARD / FORWARD DRAG **40 APPLIES**

Repeat Section 5 above

SECTION 12 NOISE STOPS SECTION **132 APPLIES**

Repeat Section 6 above