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A PROPOSED COMPRESSION BRAKE NOISE TEST PROCEDURE

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ABSTRACT
Compression brakes are typically installed on heavy trucks, and operated when the truck is going downhill, although drivers sometimes use them on level ground. The noise generated by compression brakes can be a source of excessive traffic noise. A test procedure is required in order to understand compression brake noise, develop improvements, and form the basis for regulation of brake noise. The challenge in developing a brake noise test procedure is to design a test which is simple and repeatable, while accurately simulating the noise generated under normal operating conditions. The test method proposed here is based on the standard ISO 362 acceleration driveby test. In the new procedure, an unladen truck enters the test track at high idle (maximum achievable engine speed), and decelerates past the microphones with the compression brake on. Extensive test results demonstrate that a relatively low speed test with an unladen truck provides a valid simulation for the brake noise of a fully laden truck going down a hill. The repeatability of the proposed test is also demonstrated, along with the sensitivity of the results to changes in test parameters.

INTRODUCTION

Compression brake noise has been an issue of concern in many communities. As a result, government agencies in several countries have implemented local bans on compression brake operation, and there have been threats of national bans (1). Manufacturers and operators of trucks have resisted compression brake bans. Reducing a truck's braking capacity can cause a safety problem, particularly in areas with steep hills. Legislation is now being considered in Australia to limit compression brake noise. Since a simple ban is not compatible with safety, the legislation must set noise performance standards for compression brakes. However, to date there is no standard way of measuring compression brake noise. A test procedure is required in order to achieve an understanding of compression brake noise, to aid in the development of improvements, and to form the basis for regulation. The challenge is to develop a brake noise test procedure which is simple and repeatable, but which accurately simulates the noise generated under normal operating conditions. A successful brake noise test procedure would provide a tool for product development engineers as well as regulators. It would also be very helpful for both manufacturers and regulators if a standard test procedure could be implemented on a world-wide basis, to avoid complexity and duplication of effort.

Compression brakes work by causing a diesel engine to operate as an air compressor, thus absorbing power. Air is drawn into the cylinder and compressed. Near top dead center, when fuel would normally be injected, the exhaust valve is opened. The energy stored in the compressed air is dumped into the exhaust system, rather than recovered during the expansion stroke. Under compression brake operation, an engine can absorb roughly the same power it is capable of producing under full load. This braking power can prevent overheating of the truck and trailer brakes when traveling down a long hill. However, one side effect of compression brake operation is that high pressure pulses are discharged from the cylinders into the exhaust system. This can produce excessive noise, particularly if the muffler is removed, deteriorated, or not designed to work with a compression brake. The pressure pulses from compression brake operation are significantly higher than those from full power operation, so compression brakes can create exhaust noise levels significantly higher than those seen under full power.

PROPOSED COMPRESSION BRAKE NOISE TEST PROCEDURE

The proposed compression brake noise test procedure is designed to provide an accurate representation of "real world" braking noise in a controlled test track environment. Initial experiments on compression brake noise testing are described in (1). The compression brake test procedure described here is modeled after the ISO 362 driveby test (2). ISO 362 is the basis of many driveby noise regulations around the world, such as those of the European Union (3), Australia (4), and Japan.

In the standard ISO 362 acceleration driveby test, the unladen truck approaches line AA' in a chosen gear at a constant speed, as shown in Figure 1. Full throttle is applied at line AA', and the truck accelerates past the microphones. Full throttle is maintained until the rear of the truck passes the line BB'. The maximum A weighted sound pressure level is recorded as the truck goes past the microphones, using "fast" response.

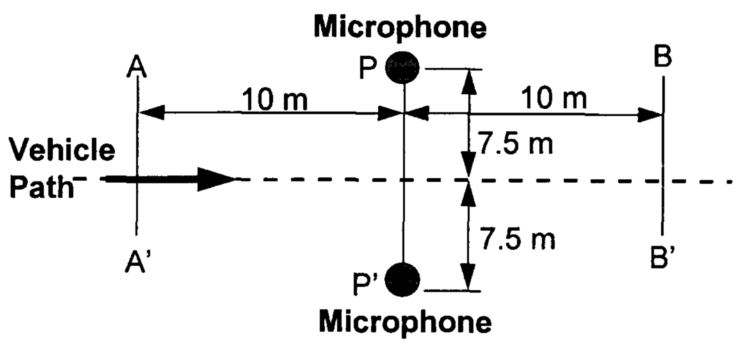

Figure 1. ISO 362 driveby noise test site layout.

The proposed compression brake noise test is run using the same test site as the ISO 362 test, and to the extent possible, the procedure is based on the acceleration test. The proposed test requires that:

- the vehicle approaches line AA' at full throttle and maximum engine speed;
- the approach is long enough to stabilize engine speed and turbo boost before line AA';
- the throttle is released at a point chosen to cause compression brake engagement halfway between line AA' and line PP';
- the test is run in the highest gear which allows an entry speed at or below 55 km/h;
- and a minimum of two passes are averaged, and the average result is reported.

A steady state approach at full throttle ensures uniform compression brake actuation. Having the brakes come on halfway between lines AA' and PP' is intended to maximize the "bark", or subjectively unpleasant noise of the compression brakes, without emphasizing the subjectively benign brief burst in noise at the instant of brake actuation. Testing in the highest gear which allows an entry speed at or below 55 km/h will reduce test complexity and give more consistent, higher noise levels, as will be shown below. Averaging several passes further improves the accuracy of the test result. Other details of the proposed compression brake noise test can be found in (5).

CORRELATION TESTS

A series of tests was created to establish a correlation between on-highway compression brake noise and the noise measured by the proposed procedure. Objective sound pressure levels were measured, and recordings for subjective analysis were made. The jury for the subjective testing consisted of six NVH engineers. Three factors distinguish typical on-highway compression brake operation from the situation on a driveby test track: on a highway there are hills, the truck is often fully laden, and vehicle speeds are usually higher than on a driveby track. Tests were designed to explore the impact of each factor on the correlation of driveby track and on-highway brake noise.

Two trucks and engines were used for this work: a conventional truck with a 525 HP Cummins N14 Plus and an 18 speed transmission, and a cabover with a 400 HP Cummins M11 Plus and a 9 speed transmission. Both trucks weighed about 18,000 pounds in unladen, or "bobtail" form (e.g., without a trailer), and weighed 80,000 pounds with a fully laden trailer. The standard OEM exhaust muffler was used for all tests reported in this paper.

In addition to the ISO 362 acceleration driveby test and the proposed compression brake test, special tests were used to compare brake noise under fully loaded and "bobtail" conditions. These tests included an acceleration test under full throttle, a compression braking test, and a coasting test. In each test, the ISO 362 microphone locations were used, and the truck was operated so that the engine was at its rated speed of 2100 RPM when the truck passed the microphones. Thus, each test had the engine at 2100 RPM near the microphones under one of three conditions: full throttle, zero throttle, and compression brake operation.

The first set of tests was run using a fully laden truck to correlate noise under downhill and level conditions. These tests were run in two different gears to achieve different road speeds. The downhill test was conducted on a highway at a location with a 4% grade. The level ground test was conducted on an unused airport runway. The two test sites had variations which can influence the test results. The state highway was paved with unsealed, non-porous asphalt, and some nearby slopes and trees may have provided some reflections. The airport runway was paved with old, very porous asphalt, and there were no reflective surfaces nearby.

Figures 2 and 3 display the results for the fully laden N14 and M11 powered trucks both on the hill and on level ground. Noise levels measured on the road, with its more reflective surface, tend to be higher than levels measured at the airport on level ground. At the higher speed, both trucks have noise levels within 2 dB for all three conditions: coasting, acceleration, and braking. At the lower speed, the N14 coasting condition is significantly quieter than either acceleration or braking, both on the hill and on level ground. However, the M11 truck at low speed has a coasting noise level on the hill similar to the acceleration and braking levels.

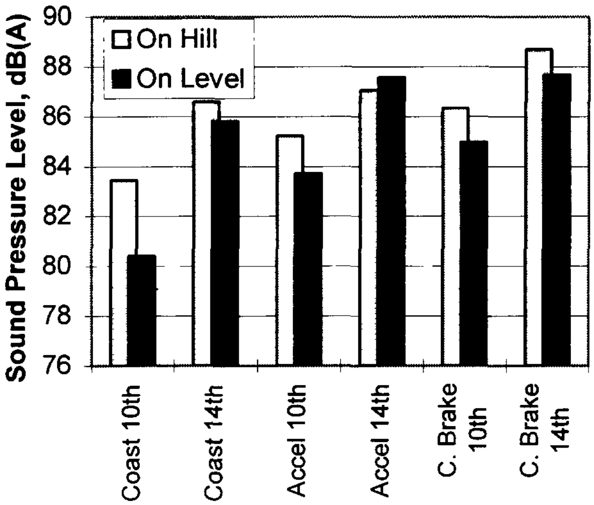

Figure 2. Comparison of N14 truck coasting, acceleration, and braking noise in two gears (34 and 64 km/h entry speed).

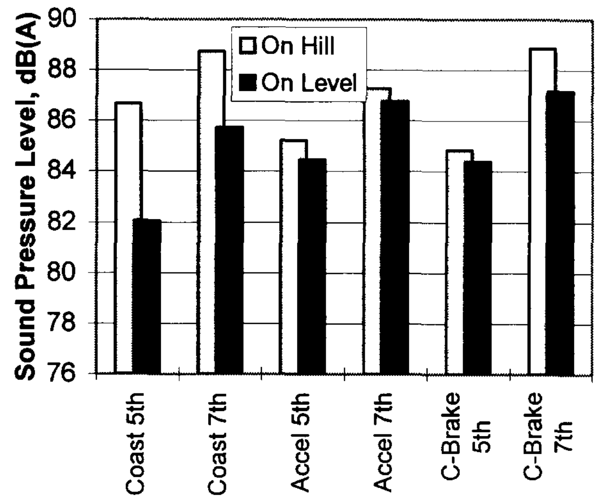

Figure 3. Comparison of M11 truck coasting, acceleration, and braking noise in two gears (35 and 69 km/h entry).

The M11 and N14 results were evaluated subjectively. The jury determined that compression brake operation was detectable, but tire noise dominated the passby noise, particularly at the higher road speeds. There was no significant subjective difference between the downhill and level ground recordings except for higher levels of tire noise on the downhill section. This result can be explained by the difference in road surface between the two test sites. Therefore, there is no need to conduct compression brake tests on a hill. At lower road speeds, the compression brake noise is similar in character to the brake noise at high speeds, but more distinct, because there is less masking by tire noise. This result suggests that a relatively low speed test for compression brake noise may be desirable, since brake noise is thus emphasized.

Noise measurements on the airport runway were used to compare the noise levels of fully

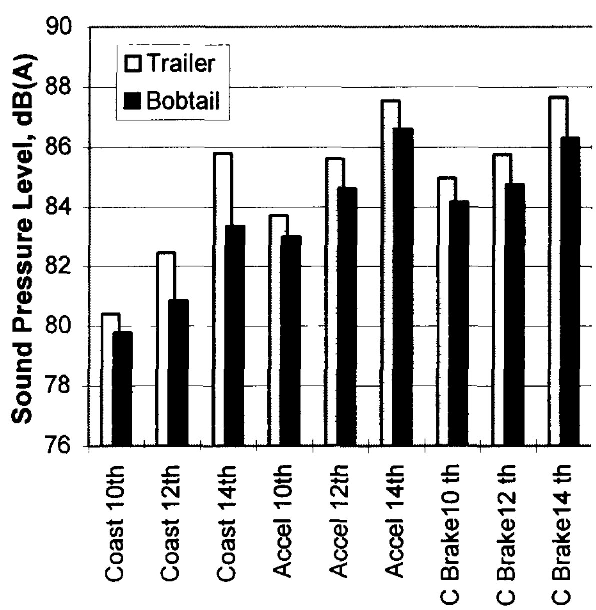

Figure 4. Comparison of N14 truck noise levels in fully laden and unladen condition at three entry speeds.

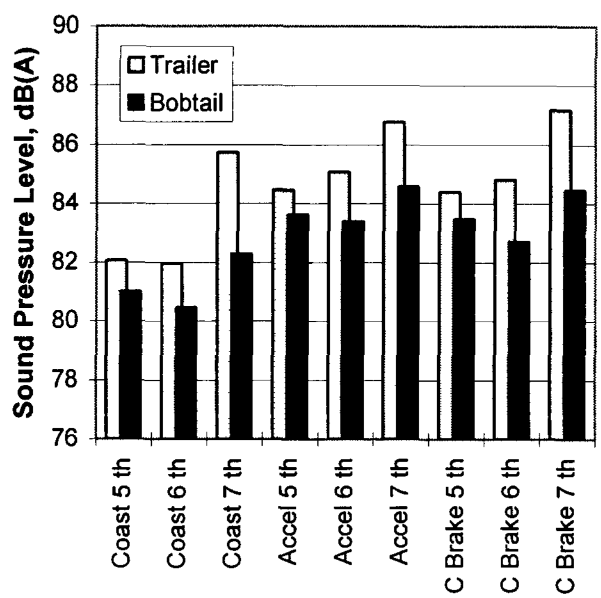

Figure 5. Comparison of M11 truck noise levels in fully laden and unladen condition at three entry speeds.

laden and "bobtail" trucks on level ground. Three configurations were tested: coasting, acceleration, and brake operation. In each case, the engine was operating at 2100 RPM as the truck passed the microphone. Figures 4 and 5 show the results for the two trucks in three gears. The gears tested here provide the same road speeds as shown in Figures 2 and 3, plus an intermediate speed. The most significant differences between loaded and "bobtail" test results occur at high speeds, where tire noise from the loaded trailer is substantial. At the lowest test speeds, the difference in noise between the laden and unladen conditions was less than 1 dB.

Recordings of the tests shown in Figures 4 and 5 were evaluated subjectively. The primary difference between the laden and unladen results was that the bobtail tests produced less tire noise. Compression brake noise is thus more distinct when tested on an unladen truck. The character of the compression brake noise is identical between the laden and unladen tests, except for the fact that the vehicle speed drops faster during the unladen test. As a result, a wider range of engine speed is covered during the unladen test. To summarize the correlation test results: it has been shown that compression brake noise can be best measured on level ground at low speeds using an unladen truck. This result allows the use of a simple test procedure based on ISO 362.

SENSITIVITY ANALYSIS

There are many parameters which can influence noise levels measured during a normal acceleration driveby test (6). Many of these parameters also apply to the proposed compression brake noise test procedure. Two parameters are unique to the proposed test: the engine entry speed, and the location where the compression brakes engage. The sensitivity of the noise results to these two parameters must be studied for two reasons. First, the test procedure might need to be modified to make it less sensitive. Second, the accuracy of the test needs to be understood.

Results presented in this section were run on an ISO 362 driveby test track with a smooth concrete surface. This is a more reflective surface than that of the airport runway. The data in this section was taken according to the proposed procedure, while the previous tests were designed to have the engine at rated speed when the front of the truck passed the line between microphones. Thus, results presented here are not directly comparable with previous results.

The first parameter of interest in compression brake testing is high idle speed. Many engines are sold with a given rated power but a choice of maximum speeds. Some engines allow the owner to select the maximum speed within a factory set range. Some engines offer a choice of isochronous and droop governors. With an isochronous governor, the maximum speed is only 20 to 30 RPM higher than rated speed. Droop governors allow high idle speeds of approximately 200 RPM above rated speed. As a result, a given engine design may be tested over a range of high idle speeds, depending on the rating or even on the customer's choice.

Figures 6 and 7 show the effect of entry RPM on compression brake noise over a range of entry road speeds (gears). Both trucks show a similar sensitivity to entry RPM. In general, the noise level achieved on the proposed brake test declines by about 0.8 dB per 100 RPM engine speed reduction, independent of the entry road speed. This effect has also been compared on a wider range of engines (7). The variation between different engine and compression brake designs was found to be a more important factor than the variation in maximum engine speeds, which covered a range of 450 RPM in the engines tested in (7). Reducing engine rated speed

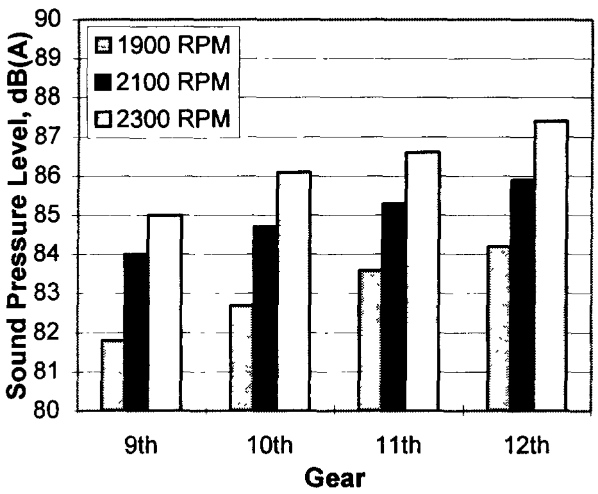

Figure 6. N14 brake noise levels in four gears at three entry speeds.

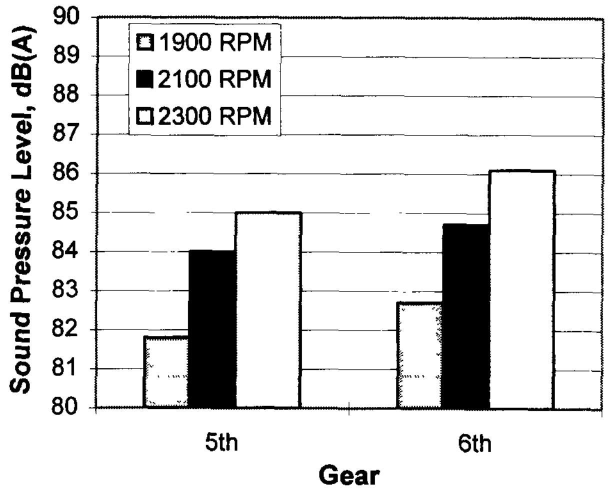

Figure 7. M11 brake noise levels in two gears at three entry speeds.

is a well known technique for reducing acceleration driveby noise without changing the design, so it is no surprise that the same approach works for reducing compression brake noise.

The second parameter of interest is the location at which the compression brakes engage. Figure 8 shows the range of brake engagement positions tested, where the position is measured with reference to the front of the truck. The vertical exhaust outlets of the test trucks are located about 4m behind the front bumper, so the exhaust outlets are actually closest to the microphones at the instant of brake engagement during the +5m test.

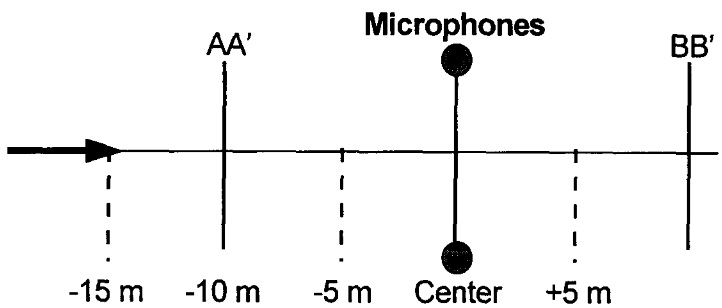

Figure 8. Brake engagement positions used for the sensitivity study.

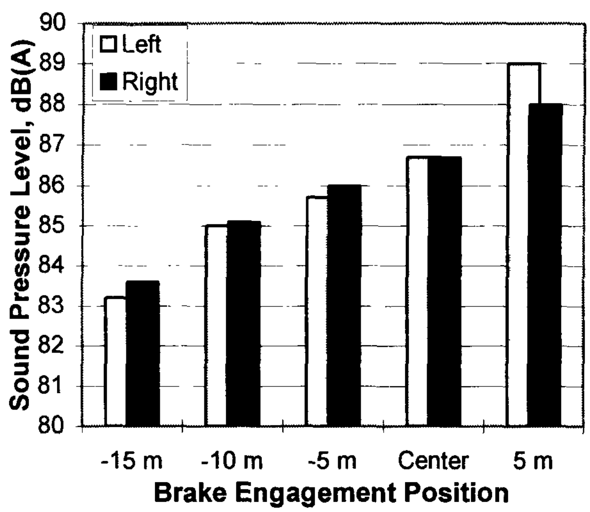

Figure 9. N14 brake noise levels vs. position in 10th gear (37 km/h entry speed)

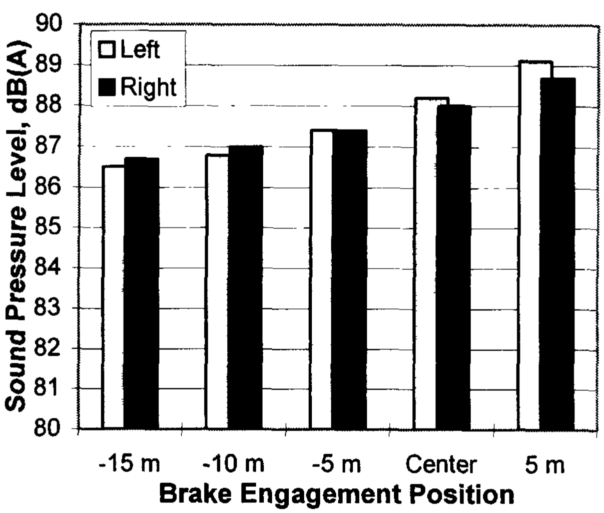

Figure 10. N14 brake noise levels vs. position in 12th gear (54 km/h entry speed)

Figures 9 through 12 show results of the proposed compression brake noise test on the N14 and M11 powered trucks, over a range of brake engagement positions. In most cases, the noise levels progressively increase as the brake engagement is delayed. In the lower gears, the range of noise levels is wide. For the N14 in the lower gear, the test result varies nearly 6 dB(A) over the range of engagement positions. For the M11, the difference over the range of engagement locations is 3.7 dB(A) in the low gear. However, in the higher gears, the range of noise levels is reduced to 2.5 dB(A) for the N14 and 1.4 dB(A) for the M11.

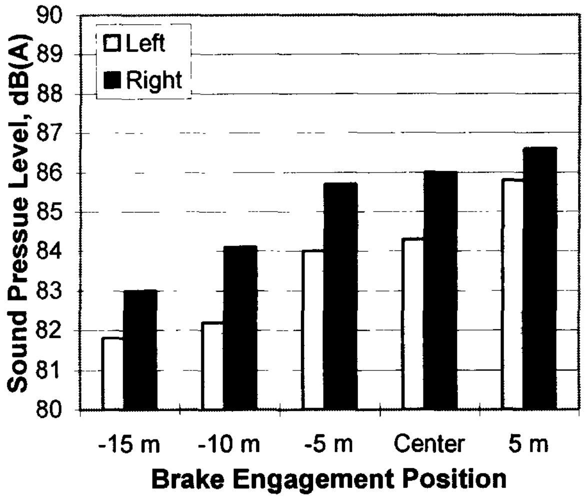

Figure 11. M11 brake noise levels vs. position in 5th gear (38 km/h entry speed)

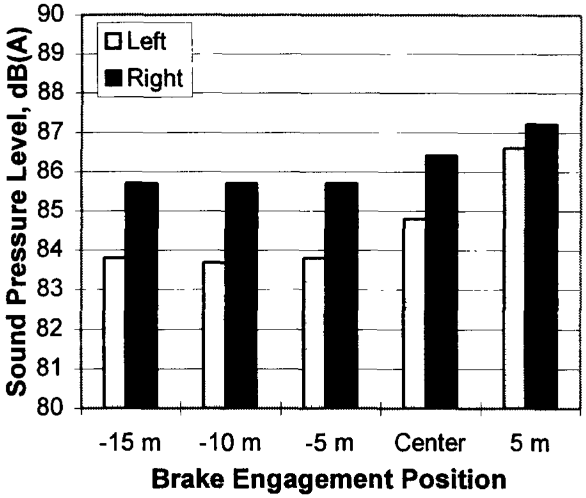

Figure 12. M11 brake noise levels vs. position in 6th gear (54 km/h entry speed)

REPEATABILITY

The proposed test procedure must demonstrate acceptable repeatability in order to be a useful development and regulatory tool. Little variability should be introduced by a steady state approach at maximum engine speed. There is some sensitivity to the position where the compression brake engages, and 1 or 2 meters of error can be expected under normal test conditions. The use of higher entry speeds of around 50 km/h help minimize this sensitivity, which amounts to about 0.1 dB per meter of error, based on the data in Figures 10 and 12. Other sources of error should be similar to or less than those found with the acceleration driveby test (6), which has acceptable repeatability. Several 10 pass brake tests were conducted according to the proposed standard. The average standard deviation of these tests was 0.3 dB(A), which is also the typical standard deviation of acceleration tests (6).

TRANSIENT vs. STEADY STATE NOISE LEVELS

From the results shown so far, it is not at all clear that the choice of having the compression brakes engage 5m before the microphone line is the best choice. Since the purpose of the test is to emphasize compression brake noise, would it not be better to have the brakes engage at the point which produces the maximum noise level? Another test was conducted in order to better understand the relationship between compression brake noise and the location on the track where the brakes are engaged. A microphone was mounted on the truck near the outlet of the exhaust pipe, and noise levels were recorded as a function of time.

The results of this test were similar for both engines. Figure 13 shows a representative result. The noise level is steady at about 96 dB(A) during the approach. There is a sharp spike up to 112 dB(A) at the instant of brake engagement, and then a relatively steady level of brake noise around 105 dB(A) after the spike. Falling engine speed finally causes the compression brake noise levels to decline after about 3 seconds of brake operation. The noise level would hold steady for much longer in a loaded truck, or if the truck is going down a hill. Subjectively, the engagement spike (which sounds like a "pop") was found to be less objectionable than the steady state brake noise, possibly because the engagement spike has a short duration. It therefore makes sense to choose a brake engagement location which does not emphasize the brief noise spike when the brakes are engaged.

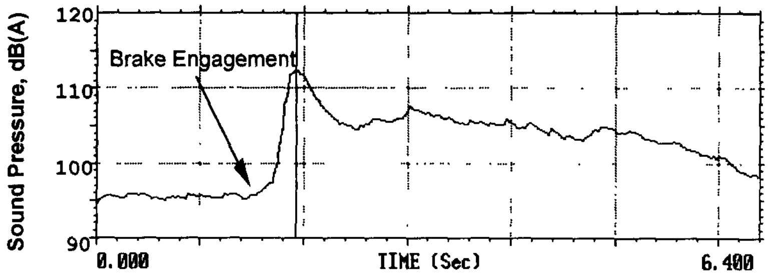

Figure 13. Noise level at the M11 exhaust outlet during a brake test. Bobtail truck, 54 km/h entry speed.

CONCLUSIONS

Compression brake noise measured with the proposed procedure has the same subjective character as that observed with a fully laden truck going down a hill at highway speeds. The proposed test procedure emphasizes compression brake noise by reducing the effect of tire noise. A moderate (50 - 55 km/h) road speed at the beginning of the test provides the best compromise between limiting test variability and reducing the effect of tire noise. Since the brief noise spike at the instant brakes are engaged is not an important source of annoyance, the test has been designed to concentrate on steady state brake noise.

The results achieved in the tests reported here show that compression brake noise can be measured on level ground, at low speed, and with an unladen truck while accurately representing the brake noise experienced on the road. The proposed test procedure has been shown to be representative, repeatable, and simple. This makes it an excellent tool for development engineers as well as for potential regulators.

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