Health and Safety Executive

Noise emission data for hand-held concrete breakers

Prepared by the **Health and Safety Laboratory**
for the Health and Safety Executive 2007

RR604
Research Report

HSE

Health and Safety Executive

Noise emission data for hand-held concrete breakers

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A programme of experimental work was carried out for a sample of six new concrete breakers:

- To assess the test method defined in the Noise Emission in the Environment by Equipment for use Outdoors Regulations 2001 (NEEEOR 2001) for usability and repeatability;
- To compare measured noise emission values with manufacturers' declared noise emission values, and with the noise generated by the same tools during simulated real-use tests;
- To establish whether declared noise emission data can be used as an indicator of noise hazard.

The declared noise emission values could not be verified in the majority of cases. This may be due in part to differing interpretation of the defined test method. Omissions and technical difficulties in the defined test method are identified. Despite differences in test-generated data for some of the breakers, in real use there were no significant differences between the noise emission of the breakers.

The real use noise emission values were generally higher than the noise emission values from the defined test method. This is probably because the defined test method looks only at noise emitted by the breaker itself, and not noise generated by the machine/inserted tool/work surface interaction.

In general therefore, using manufacturers' declared noise emissions as the basis of selecting/purchasing a concrete breaker will not reliably result in the selection of a tool that is low- or lower-noise in conditions of real use.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the author alone and do not necessarily reflect HSE policy.

HSE Books

First published 2007

Acknowledgements

The author gratefully acknowledges those who assisted in this project, in particular the tool manufacturers and suppliers who provided the tools, Mr John Lowe and Mr Tony Malkin who provided invaluable assistance during construction of the standard test rig, and Mr Russ Bremner who provided advice on how to define a realistic simulated test.

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EXECUTIVE SUMMARY

Objectives

Standards have been developed in support of the EU Machinery Directive that define how noise emission values should be obtained for different machine or tool types. Ideally these standard tests should:

- Provide noise emission data that is representative of the expected noise emission when in normal use;
- Allow tools of the same type to be compared;
- Identify low-noise tools, thereby highlighting successful low-noise designs.

In practice it can be difficult to design standard tests that are based on realistic operations and which give repeatable and reproducible results. It is common therefore for standard tests to be based on artificial operations. However there is concern that the resultant standard noise emission data may not reflect the noise generated by the tool during normal use. There is a need therefore to evaluate standard noise emission tests.

The purpose of the work reported here was:

- To determine noise emission values for a sample of new concrete breakers using the method defined in the Noise Emission in the Environment by Equipment for use Outdoors Regulations 2001 (NEEEOR 2001);
- To evaluate the practicality of the standard test method and the repeatability of resultant noise emission data;
- To compare noise emission data from standard tests with the noise generated by the same tools on a selection of work surfaces during simulated real-use tests;
- To establish whether noise emission data from standard tests can be used to predict noise exposure during normal use and to correctly rank the tools in order of noise risk.

Main Findings

The Health and Safety Laboratory (HSL) verified the manufacturers' declared emission values for two of the six breakers tested. HSL used the standard test method defined in NEEEOR 2001 and applied the criteria in BS EN ISO 4871 for verification. The manufacturers' declared emission values and the HSL measured emission values did not exceed the maximum permissible sound power levels specified in NEEEOR for five of the six tools tested.

Omissions and technical difficulties with the standard test method made it difficult to comply with all of the requirements of NEEEOR 2001 when constructing the noise emission test rig at HSL. It is possible that these difficulties resulted in some of the differences observed between the manufacturer's declared and the HSL measured noise emission data.

In general, the measured emission data using the standard test method was between 2 and 7 dB lower than the normal use sound power levels. This was probably due to the additional noise generated during the breaking process (interaction of steel and surface), which dominates real use sound power levels. The sound pressure levels measured at the operator's position during the standard emission tests were either comparable with, or overestimated, the normal use sound pressure levels by up to 5 dB.

The standard test method gave reproducible results. However the measured emission values did not differentiate the relative noise hazard associated with individual breakers during normal use because the noise levels they generated during simulated real use tests did not significantly differ: the mean sound pressure levels were between 92 and 95 dB(A), the mean sound power levels were between 111 and 113 dB(A).

All of the breakers tested were fitted with silencers that enclosed the main body of the tool. According to one breaker manufacturer, most silencers share the same design although there may be differences in the quality of the materials used to make the silencer. The tool with the lowest measured emission value used a tappet bush, which the manufacturer claimed was effective at reducing noise and had a long life. It is not clear whether this feature is unique in breaker design. None of the breakers were supplied with information that suggested they were designed with low noise features.

Tests comparing standard and vibration reduced steels, showed that vibration reduced steels reduced the noise generated by heavier tools by between 2 and 3 dB. However the vibration reduced steels also appeared to increase the noise levels generated by some breakers, and their performance seemed to be dependent on the surface upon which they were used.

The simple methods used to assess breaker productivity did not identify any significant differences between the different breakers; nor between standard and vibration reduced steels. It is possible that a more complex test is needed to investigate breaker productivity, which is likely to involve longer periods of breaking under more realistic conditions (eg breaking up a concrete edge).

Recommendations

We recommend that the DTI is informed of the omissions and technical difficulties encountered with the noise emission test for concrete breakers defined in NEEEOR 2001. It may be possible to amend the test code (ie as a technical update) in a way that does not change the requirements of the regulations.

Further work is recommended for investigating the standard test defined in NEEEOR 2001. In particular, the use of the test method for breakers with fixed handles, and the effect of the applied vertical force on the resultant measured noise emission values require additional research.

Measurements made in accordance with the requirements of NEEEOR 2001 resulted in small sample sizes; high statistical values are needed for significance when sample sizes are small. Statistical analysis should be repeated with much larger sample sizes in order to investigate further the effect of the surface type on the level of noise generated and the performance of vibration reduced steels.

1 INTRODUCTION

1.1 DECLARATION OF NOISE EMISSION

The EU Machinery Directive [1], implemented in the UK as the Supply of Machinery (Safety) Regulations 1992 as amended 2005 [2], places duties on machine manufacturers and suppliers to design and construct machinery in such a way that noise emissions are reduced to the lowest level taking account of technical progress and the availability of techniques for reducing noise, particularly at source. There is also a requirement that manufacturers and suppliers provide information on the airborne noise emissions of their products. The purpose of declaring such information is to allow purchasers and users of machinery to make informed choices regarding the safety of a potential purchase.

Standards have been developed in support of the EU Machinery Directive that define how noise emission values should be obtained for different machine types. Ideally these standard tests should provide noise emission data that is representative of the expected noise emission in normal use, allow tools of the same type to be compared, and identify low-noise tools thereby highlighting successful low-noise designs. In practice it can be difficult to design standard tests that are based on realistic operations and which give repeatable and reproducible results. It is common therefore for standard tests to be based on artificial operations. However there is concern that the resultant standard noise emission data may not reflect the noise generated by the tool during normal use. There is a need therefore to evaluate the standard noise emission tests.

1.2 NOISE EMISSION OF HAND-HELD CONCRETE-BREAKERS

Some tools, including hand-held concrete breakers, are covered by both the EU Machinery Directive and the Noise Emission in the Environment by Equipment for use Outdoors Directive [3], implemented in the UK as the Noise Emission in the Environment by Equipment for use Outdoors Regulations (NEEEOR) 2001 [4]. The method for measuring airborne noise emissions for concrete breakers is given in NEEEOR 2001.

For certain categories of machine, including concrete breakers, NEEEOR 2001 require that for individual machines the manufacturer declares a guaranteed sound power level that does not exceed the applicable permissible sound power level laid down in NEEEOR. The guaranteed sound power level is defined as a sound power level that includes an allowance for uncertainties in the determination of sound power level due to production variation and measurement procedures [3]. The manufacturer is responsible for determining the level of uncertainty and must include it in the calculation of the guaranteed sound power level. Products subject to limit values will have an upper limit for the guaranteed sound power level. Guaranteed sound power levels must be lower than or equal to the noise limit value. In all cases, the guaranteed sound power level as indicated on the product must not be exceeded in a standardised test.

1.3 OUTLINE OF WORK

The aims of the work reported here were:

- To determine noise emission values for a sample of new concrete breakers using the method defined in NEEEOR 2001;
- To evaluate the standard test method in terms of its practicality and the repeatability of resultant noise emission data;

- To compare standard noise emission data with normal use noise generated by the same tools on a selection of work surfaces during simulated real-use tests;

- To establish whether noise emission data can be used to predict noise exposure during normal use and to correctly rank the tools in order of noise risk.

It was originally planned to obtain standard noise emission data using existing test facilities in the UK that met the requirements of NEEEOR 2001. However during the course of the project the identified test facilities became unavailable. A facility for testing the noise emission of concrete breakers was therefore constructed on the Health and Safety Laboratory (HSL) site in Buxton. It conformed to the requirements of NEEEOR 2001. A number of concrete breaker manufacturers and suppliers agreed to loan HSL tools for testing. Noise emission data for each breaker was obtained in accordance with the test method described in NEEEOR 2001. Simulated real tests were also carried out to obtain normal use sound power levels and sound pressure levels during realistic tasks in a repeatable laboratory environment where factors such as air supply, surface type and task could be more easily controlled.

1.4 TERMINOLOGY FOR EMISSION DATA

The guaranteed noise emission data declared by the manufacturer and supplied with the concrete breaker is referred to as the *declared emission*.

The noise emission measured by HSL in accordance with the requirements of NEEEOR 2001 is referred to as the *measured emission*.

2 TOOLS TESTED

Six new breakers were obtained for testing; they are described in Table 1. All the tools were pneumatic and fitted with a silencer (muffler). All were fitted with anti-vibration handles except Tool B.

Table 1: Tools obtained for testing

Tool	Chuck size mm	Weight kg	Length mm	Max working pressure bar	Air consumption l/min	Impact frequency Hz	Guaranteed declared noise emission dB(A)
A	32 hex x 160	27.5	691	7	1920	23	109
B	32 hex x 160	24.5	691	7	1920	23	109
C	32 hex x 160	25	735	6	1250	23	107
D	32 hex x 160	32	712	6	1560	16	106 (*a*=105; *K*=1)
E	32 hex x 160	30.5	735	7	1700	20	111
F	25 hex x 108	21	659	7	1300	22	108

All the tools, except Tool D were supplied with declared single-number noise emission values.

Tool D was supplied with declared dual-number noise emission values *a* and *K*; *a* is a noise emission value determined directly from measurement and *K* is the uncertainty associated with those measurements. The single-number noise emission value is (*a* + *K*) and represents the upper limit which values from repeated measurements are unlikely to exceed at a given confidence level.

In addition to the guaranteed noise emission values given in Table 1, Tools E and F were supplied with single-number noise emission values, mean measured noise values (these were 1 dB lower than the guaranteed noise emission values given in Table 1) and certified noise levels (these were 1 dB higher than the guaranteed noise emission values). The intended use of these noise levels is unclear.

The guaranteed noise levels for the six tools tested were between 106 and 111 dB, ie the difference between the lowest and highest declared noise emission value was only 5 dB.

3 STANDARD NOISE EMISSION MEASUREMENTS

3.1 NOISE MEASUREMENTS

NEEEOR 2001 cites basic noise emission standards and general supplements to these standards, for measuring the sound pressure level on a measurement surface enveloping the source and for calculating the sound power level produced by the source. For concrete breakers the basic noise emission standard is EN ISO 3744: 1995 [5].

Simultaneous sound pressure level measurements were made at six points positioned on a hemisphere as shown in Figure 1.

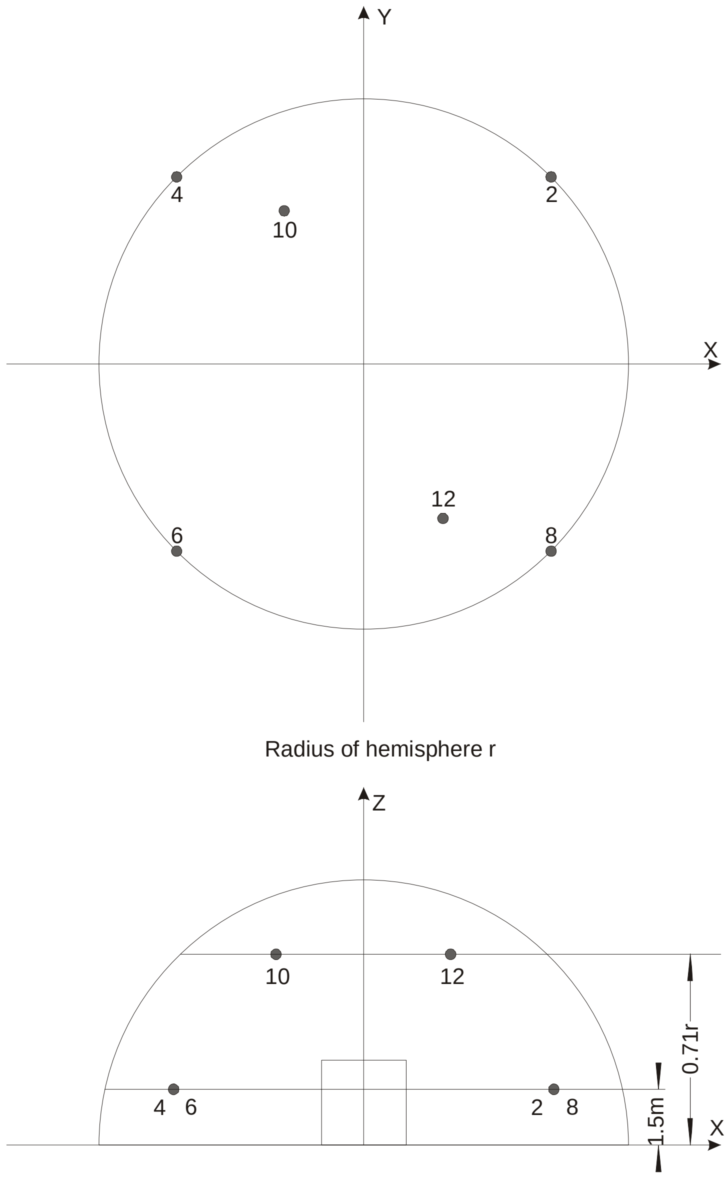

Figure 1: Microphone positions on hemisphere

The microphones and associated equipment used for these measurements is listed in Appendix A. The mass of each of the breakers being tested was greater than 10 kg, therefore the radius of the hemisphere was 4 m in accordance with the requirements of NEEEOR 2001. The coordinates of the six microphone positions are given in Table 2.

Table 2: Coordinates of microphone positions (in metres) on hemisphere with radius 4 m

Microphone position	x m	y m	z m
2	2.8	2.8	1.5
4	-2.8	2.8	1.5
6	-2.8	-2.8	1.5
8	2.8	-2.8	1.5
10	-1.08	2.6	2.84
12	1.08	-2.6	2.84

The noise generated by the concrete breakers during the tests was steady, therefore the A-weighted surface sound pressure level L_{pA} was calculated from the energy average of the six measurements:

$$L_{pA} = 10 \log_{10} [1/6 (10^{L1/10} + 10^{L2/10} + 10^{L3/10} + 10^{L4/10} + 10^{L5/10} + 10^{L6/10})] \text{ dB}$$

where *L1*, *L2*, *L3*…..*L6* were the A-weighted sound pressure levels at each of the six measuring points.

It was not necessary to make corrections for background noise because the difference between the surface sound pressure level with and without the concrete breakers in operation was greater than 15 dB; it was typically 30 dB. Background noise included the noise generated by the compressor used to power the breakers, which was positioned 24 m from the test rig.

NEEEOR 2001 requires the concrete breakers to be tested on a reflecting surface of concrete or a non-porous asphalt. The breakers were tested on a concrete surface; when this is the case, the environmental correction is set to zero.

For each breaker tested, the surface sound pressure level was determined at least three times, or until two of the determined values were within 1 dB of each other. The surface sound pressure level L_{pA}' used to calculate the sound power level was taken as the arithmetic mean of the two highest A-weighted surface sound pressure levels that were within 1 dB of each other.

The A-weighted sound power level L_{WA} was calculated from:

$$L_{WA} = L_{pA}' + 10 \log_{10} (S/S_o)$$

where S is the surface area of the hemisphere in m^2 (ie $2\pi r^2$), and $S_o = 1$ m^2. For a hemisphere of radius 4m, $10 \log_{10} (S/S_o)$ is 20.0 dB.

3.2 CONSTRUCTION OF STANDARD TEST RIG

The test rig for obtaining noise emission data for concrete breakers was constructed in accordance with the requirements of NEEEOR 2001. Figure 2 shows the test rig.

Figure 2: NEEEOR 2001 standard test rig at HSL for concrete breakers

The concrete breaker was placed in a vertical position in the centre of a hemispherical array of microphones. A compressor situated 24 m from the test rig was used to supply compressed air to the breaker via an in-line regulator. The regulator was used to ensure that the breaker was operated at the maximum working pressure specified in the instructions supplied with the tool.

In accordance with NEEEOR, the breaker was coupled to a tool embedded in a 0.6 x 0.6 x 0.6 m concrete block during the test. This block was placed in a concrete pit sunk into the ground. A concrete screening slab (>100 kgm^{-2}, 45 mm deep) covered the block so that the upper surface of the screening slab was flush with the ground. In order to make the manual handling of the screening slab safe and manageable, the screening slab used in the HSL test rig comprised two parts as shown in Figures 3a and 3b. All gaps in and around both parts of the screening slab were made as small as possible; any remaining gaps were sealed with sound absorbent material during testing.

Figure 3a: Screening slab constructed in two halves – one half fitted over concrete block to show construction and placement

Figure 3b: Both parts of screening slab fitted over concrete block

Four concrete blocks were constructed using the following mix: 450 kg ordinary Portland cement per m^3 incorporating a super-plasticiser, which acts as a powerful water-reducer resulting in a high concrete strength. This mix was an equivalent alternative to the specified C50/60; test samples were taken to ensure that the concrete had achieved the required 60 Nmm^{-2} strength at 28 days. Each concrete block was reinforced by an array of 8 mm diameter steel rods constructed as shown in Figure 4. NEEEOR 2001 requires that these rods are without ties, and that during construction of the blocks the concrete poured around the rods is thoroughly vibrated to avoid excessive sedimentation. It was impossible to construct the blocks without lightly tying the rods. To do this, some of the joints between the rods were welded together as shown in Figure 4. Only one concrete block was used for testing all the breakers. It remained structurally sound throughout the tests.

Figure 4: Lightly tied reinforcing steel rods

To avoid any parasitic noise (ie any noise at the measuring points generated by the breaker but not directly radiated by it), the concrete block was positioned on four anti-vibration mounts positioned in each of the four corners of the concrete pit. In accordance with NEEEOR 2001, the cut off frequency of the mounts was less than half the striking rate of the breakers tested; the natural frequency of the mounts was 7 Hz.

The concrete block and pit were constructed according to the dimensions specified in NEEEOR 2001, although the depth of the pit was taken as 660 mm (as specified in EU Directive 84/537/EEC [6]), not 600 mm (as specified in NEEEOR 2001). It would have been impossible to accommodate the concrete block, suitable anti-vibration mounts, required sound absorbing material, and a screening slab that was flush with the surrounding ground, in a 600 mm deep pit.

There was very little space in which to fit elastic blocks capable of isolating the block from the sides of the pit. Strips of rubber approximately 1 cm thick were positioned down each side of the block to prevent the block from making contact with the sides of the pit. A sheet of sound absorbent foam approximately 60 x 60 x 2 cm was placed over the concrete block, before the screening slab was fitted.

The breakers tested in this project used tools with two different chuck sizes: 32 hex x 160 mm and 25 hex x 108 mm. To enable the same concrete block to be used for all of the breakers, the tool was constructed in two parts fastened together by means of an intermediate piece as shown in Figure 5 and Figures 6a to 6c.

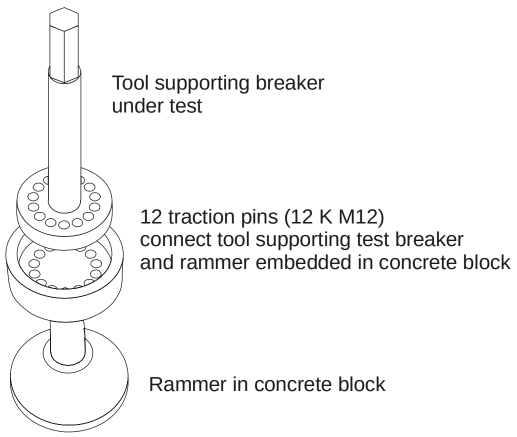

Figure 5: Sketch of intermediate piece

Figure 6a: Part of the intermediate piece embedded in concrete block (tool attached to rammer with 180 mm diameter)

Figure 6b: Embedded intermediate piece flush with surface of concrete block

Figure 6c: Part of intermediate piece fitted with tools appropriately sized for the breaker under test

3.3 METHOD USED TO SUPPORT BREAKERS

The method in NEEEOR 2001 does not specify whether the breaker shall be operated with or without an operator during emission tests. This is a significant omission. Guidance was therefore taken from the previous standard test used to measured breaker noise emission values, which is specified in the EU concrete breaker directive 84/537/EEC. In this test, "the breaker is run unattended by an operator in the manner described below:

- The breaker is operated in an upright position on the concrete block rig which is fitted with a tool shank of the correct size for the breaker under test.
- The breaker is firmly held down by a flexible device in order to give the same stability as that existing under normal operating conditions, when the tool is embedded in the material to be broken up before it fractures; the flexible device may take the form of calibrated springs or pneumatic jacks, for example."

In the HSL test rig, the breakers were held in place with a pneumatic jack supported by a steel crossbeam as shown in Figure 7. Sound pressure level measurements with and without the steel frame showed that the frame did not influence the noise levels measured at each of the microphone positions; differences were less than 1 dB. These tests were carried out using a dodecahedron loudspeaker (omni-directional) input with pink noise that was positioned in the test rig in place of the breaker.

Figure 7: Set up for supporting breaker during noise emission tests

Figure 8 shows the method used to attach the pneumatic jack to the breaker handles. The nuts were tightened so that they did not work loose during the tests. A pressure gauge connected in-line between the compressor and the pneumatic jack enabled the vertical force applied on the breakers to be controlled. The pressure gauge was located approximately 5 m from the test rig.

The breakers with anti-vibration handles were tested with the handles in the mid-position of travel as instructed by the manufacturers. This meant that the handles were fixed in or close to the horizontal position by adjusting the air supply through the jack. The applied vertical force (feed force) required to maintain the breaker handles in this mid-position was measured in the laboratory using a force platform and three test subjects. The mean value and the range of applied vertical forces obtained for each breaker are given in Table 3. The feed force required to maintain the handle of Tool D in the mid-position was much lower than for the other tools tested with anti-vibration handles. Similar results were obtained when vibration emission data for this tool were measured [7]; the design of this handle is therefore likely to be the reason that a lower feed force was needed.

Tool B has fixed handles and it was therefore difficult to determine the vertical force that was applied during the emission tests. Sufficient force was applied so that the tool did not bounce around excessively in the test rig.

The distance between the base of the breakers and the screening slab was between 10 and 15 cm depending on the breaker under test. For all tools, the axis of the air exhaust was equidistant from two microphone positions.

Table 3: Vertical force applied on breakers to maintain handles in mid-position

Tool	Applied vertical force N	
	Mean	Range
A	135	130-140
B (fixed handles)	-	-
C	193	170-210
D	58	45-65
E	153	130-175
F	152	145-166

Figure 8: Method used for attaching pneumatic jack to breaker handles

3.4 METEOROLOGICAL CONDITIONS

A summary of the meteorological conditions during the emission tests and the simulated real use tests is given in Table 4. The information was obtained from a website giving current local weather conditions in Buxton.

Table 4: A summary of meteorological conditions

Date	Temperature °C	Pressure mB	Wind speed mph	Relative humidity %
October-November 2005	STANDARD EMISSION TESTS			
	4-16	996-1035	0-11	63-74
December 2005	SIMULATED REAL USE TESTS			
	4-7	1021-1035	7-22	74-86

3.5 DATA ACQUISITION AND ANALYSIS

Microphones on tripods were located at each of the measurement positions specified in NEEEOR 2001. The microphones were connected to microphone power supplies and the output from these was input to a noise analyser (Brüel & Kjæl PULSE system) for real time analysis. Simultaneous noise measurements were made at the six microphone positions during testing using a 20 s linear averaging time. One-third octave band frequency spectra were obtained at each microphone position using the noise analyser. The sound pressure levels measured at each position were combined to give the A-weighted surface sound pressure level.

Additional measurements were made to obtain the sound pressure level at the position that would be occupied by the ear of an operator using the standard test rig. These measurements were made using a Brüel & Kjæl 2260 sound level meter.

3.6 TEST RESULTS

Table 5 contains the results of the standard noise emission tests for six concrete breakers tested using the HSL standard test rig.

Table 5: HSL measured noise emission

Tool	Surface sound pressure level dB(A)			[1]Measured emission (L_1) dB(A)	[2]Declared emission (L_d) dB(A)	[3]Verified?
	Meas 1	Meas 2	Meas 3			
A	89.7	89.5	89.4	110	109	No
B	87.2	86.6	86.2	107	109	Yes
C	86.4	87.2	87.0	107	107	Yes
D	86.7	86.8	86.8	107	106	No
E	93.8	93.9	94.1	114	111	No
F	88.5	88.8	88.3	109	108	No

1 Measured emission (sound power level) obtained using the arithmetic mean of the two highest A-weighted surface sound pressure levels

2 Declared single-number noise emission value $L_d = (a + K)$

3 Verification of the measured emission values is obtained by applying the criteria defined in BS EN ISO 4871 [8] and EN 27574-2 [9] ie is $L_1 \leqslant L_d$ [8, 9]

Table 6 shows the sound pressure levels generated at the position of the operator's ear when the breakers were run in the standard test rig.

Table 6: Sound pressure levels at the ear position during standard noise emission tests

Tool	A	B	C	D	E	F
Sound pressure level dB(A)	96.5	93.2	94.9	92.0	97.0	92.4

4 SIMULATED REAL USE MEASUREMENTS

Simulated real use tests were carried out using the six concrete breakers described in Table 1 to obtain normal use sound power levels and sound pressure levels during realistic tasks.

4.1 TEST DESCRIPTION

Three fully trained, experienced tool operators tested the breakers on concrete and tarmac surfaces at HSL Buxton. According to the manufacturers, the breakers tested here are designed for use on both of these surfaces.

A steel (tool) manufacturer recommended using a moil point on concrete and a tarmac cutter on tarmac. In practice a heavy-duty burster would be used to break up the concrete covering the test area, however it would break the surface up very quickly. Its use was considered impractical in these tests since a large number of measurements were required on the concrete surface.

Figure 9a: Standard cutter used for breaking tarmac

Figure 9b: Vibration reduced cutter used for breaking tarmac

One of the aims of the project was to investigate the methods used to reduce the noise generated by concrete breakers during normal use. The breakers were tested with standard and vibration reduced steels (moil point and tarmac cutter). Figures 9a and 9b show standard and vibration reduced tarmac cutters. According to the manufacturer, the vibration reduced steels are made by tonally tuning the steels using harmonics and fitting a collar made from a viscoelastic material.

The test area was situated roughly in the centre of an array of six microphones. The microphone positions were the same as those used for the standard noise emission tests; they are defined in Section 3.1. The compressor driving the breakers was positioned approximately 23 m from the centre of the concrete test area and approximately 27 m from the centre of the tarmac test area. Simultaneous noise measurements were made at each microphone position over a 20 s period during which time the operator was instructed to break up the surface with the breaker under test. This data was used to calculate the sound power level. The operator repeated the breaking task to enable noise measurements to be made close to the ear. A Brüel & Kjæl 2260 sound level meter was used to measure the noise as shown in Figure 10.

Figure 10: Noise measurements at the operator's ear

The operators were asked to break up the surface in and around the centre of the microphone array. For tests on both concrete and tarmac, the area of the broken test surface was not considered large enough to require the position of the microphone array to be changed. During the tests on concrete an area of approximately 4.5 m^2 was broken up; an area of approximately 5.2 m^2 was broken up during the tests on tarmac.

The operators were instructed to use the breakers as they would during normal use. The only additional information provided was how to use the breakers with anti-vibration handles. The manufacturers recommend keeping the handles in the horizontal position, which gives the user the maximum reduction in vibration. Although the operators had previous experience using breakers with anti-vibration handles, they had not been trained how to use them properly. During these simulated real tests, the breakers were operated at the maximum working pressure specified by the tool manufacturer.

4.1.1 Tests on concrete

The large area of concrete shown in Figure 11 was used to test the breakers during simulated real use tasks.

Figure 11: Concrete test area

The task consisted of breaking out the concrete to a depth of approximately 5 cm, then moving the breaker 8-10 cm to the side to start another break out. Noise measurements were made over 20 s and the number of break-outs (holes) the operator achieved in this time was counted to provide a measure of the breaker productivity. A subjective assessment of the productivity of the breakers was also carried out using a questionnaire, which was presented to the operator after each measurement on both the concrete and tarmac surfaces [10].

4.1.2 Tests on tarmac

Figure 12 shows the area of tarmac on which the breakers were tested. The task consisted of working an open face by cutting along the tarmac surface to break it up. Once the surface was broken the operator was asked to move the breaker along by a distance equivalent to the cutter width (115 mm) and repeat the task. Each break into the surface was referred to as a pass; the number of passes achieved by the operator during the 20 s measurement period was counted to provide a measure of breaker productivity.

Figure 12: Tarmac test area

The tarmac surface on which the breakers were tested was less uniform than the concrete surface; the operators commented that some parts were easier to cut up than others. The tarmac surface was broken up by one of the operators at four different positions within the microphone array. Measurements were made during these tests to determine the likely variation in measured sound power levels due to surface differences. Differences in the tarmac surface resulted in differences of up to 3 dB in the measured sound power levels.

4.2 TEST RESULTS

The sound power levels and sound pressure levels measured during the simulated real use tests are given in Tables 7a to 7c, and Figures 13a and 13b. Table 7a contains mean and standard deviation values that were obtained by combining the levels from the individual operators. The individual values obtained for each operator during the simulated real use tests are shown in Appendix B. Table 7b contains a summary of the mean sound power levels for the different measurement conditions, ie concrete, tarmac, standard, and vibration reduced steels. Table 7c contains the mean sound pressure levels for the different measurement conditions.

Table 8 contains mean sound power levels and mean sound pressure levels for each of the tools. These were obtained by combining all the data for each tool ie for individual operators, different surfaces and different steels. These mean levels take into account all the variables that may affect the noise levels generated by a breaker during normal use. They were therefore considered a good estimate of noise levels during normal use.

Table 7a: Sound power levels and sound pressure levels measured during simulated real tests

Tool	Steel	Surface	Sound power level dB(A)		Sound pressure level dB(A)	
			Mean	Std dev	Mean	Std dev
A	Standard moil	Concrete	111.5	0.7	94.5	2.2
	Vibration reduced moil	Concrete	111.4	0.6	94.0	1.3
	Standard cutter	Tarmac	110.0	0.8	90.7	1.4
	Vibration reduced cutter	Tarmac	111.2	1.5	91.0	1.2
B	Standard moil	Concrete	112.7	0.4	95.2	0.6
	Vibration reduced moil	Concrete	111.2	0.4	95.2	1.1
	Standard cutter	Tarmac	110.1	0.7	92.5	1.9
	Vibration reduced cutter	Tarmac	111.2	1.2	92.2	2.5
C	Standard moil	Concrete	112.0	1.1	95.0	2.0
	Vibration reduced moil	Concrete	111.5	0.7	95.7	1.2
	Standard cutter	Tarmac	112.1	1.3	93.1	2.2
	Vibration reduced cutter	Tarmac	-	-	-	-
D	Standard moil	Concrete	111.3	0.6	92.4	1.1
	Vibration reduced moil	Concrete	110.8	0.6	93.2	1.2
	Standard cutter	Tarmac	114.4	1.3	93.7	1.9
	Vibration reduced cutter	Tarmac	112.1	1.2	92.0	0.6
E	Standard moil	Concrete	113.5	0.9	94.0	0.3
	Vibration reduced moil	Concrete	112.2	0.6	94.6	0.3
	Standard cutter	Tarmac	113.1	0.8	94.0	0.7
	Vibration reduced cutter	Tarmac	113.4	1.1	92.8	2.0
F	Standard moil	Concrete	115.1	0.5	95.6	1.5
	Vibration reduced moil	Concrete	-	-	-	-
	Standard cutter	Tarmac	-	-	-	-
	Vibration reduced cutter	Tarmac	-	-	-	-

Table 7b: Simulated real use sound power levels

Tool	Means sound power level dB(A)			
	Concrete	Tarmac	Standard steel	Vibration reduced steel
A	111.5	110.6	110.8	111.3
B	112.0	110.7	111.6	111.2
C	111.8	112.1	112.1	111.5
D	111.1	113.4	113.1	111.5
E	112.9	113.3	113.3	112.5
F	115.1	-	-	-

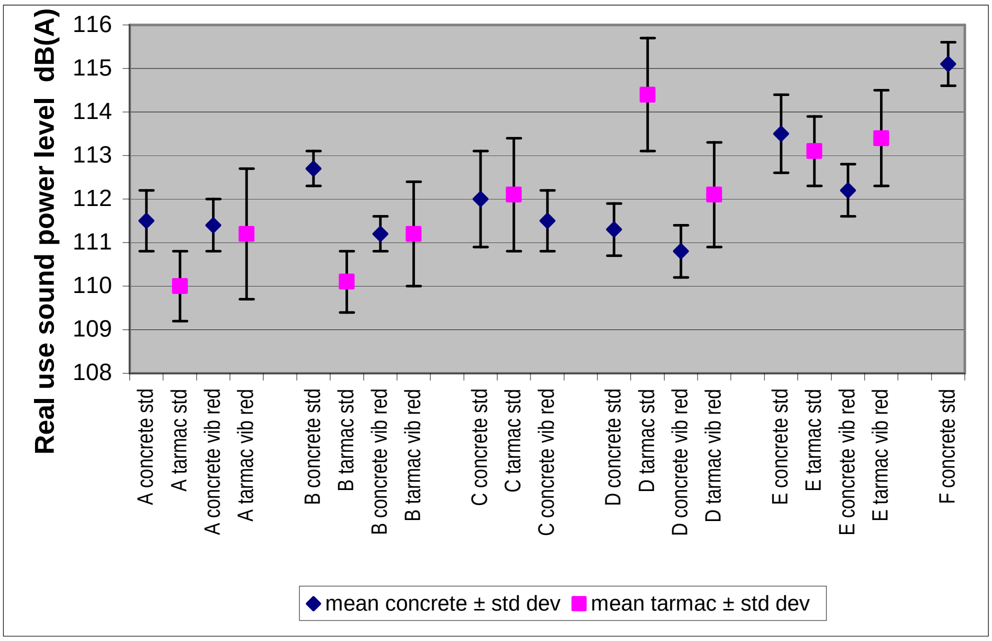

Figure 13a: Simulated real use sound power levels

Table 7c: Simulated real use sound pressure levels

Tool	Means sound pressure level dB(A)			
	Concrete	Tarmac	Standard steel	Vibration reduced steel
A	94.3	90.9	93.0	92.8
B	95.2	92.4	94.1	94.0
C	95.4	93.1	94.1	95.7
D	92.8	92.9	93.1	92.6
E	94.3	93.4	94.0	93.8
F	95.6	-	-	-

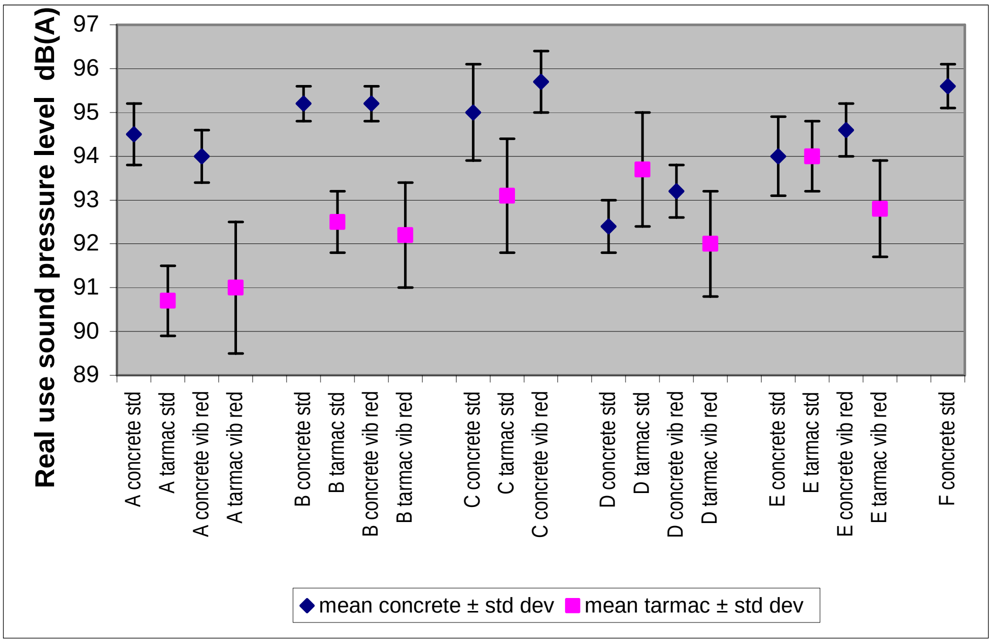

Figure 13b: Simulated real use sound pressure levels

Table 8: Mean sound power levels and mean sound pressure levels during simulated real use

Tool	Sound power level dB(A)		Sound pressure level dB(A)	
	Mean	Standard deviation	Mean	Standard deviation
A	111.0	1.1	92.5	2.2
B	111.3	1.2	93.8	2.1
C	111.8	0.9	94.6	2.0
D	112.4	1.7	92.9	1.2
E	113.0	1.0	93.9	1.2
F	115.1	0.5	95.6	1.5