Health and Safety Executive

Noise emission data for hand-held concrete breakers

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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.

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CONTENTS

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.

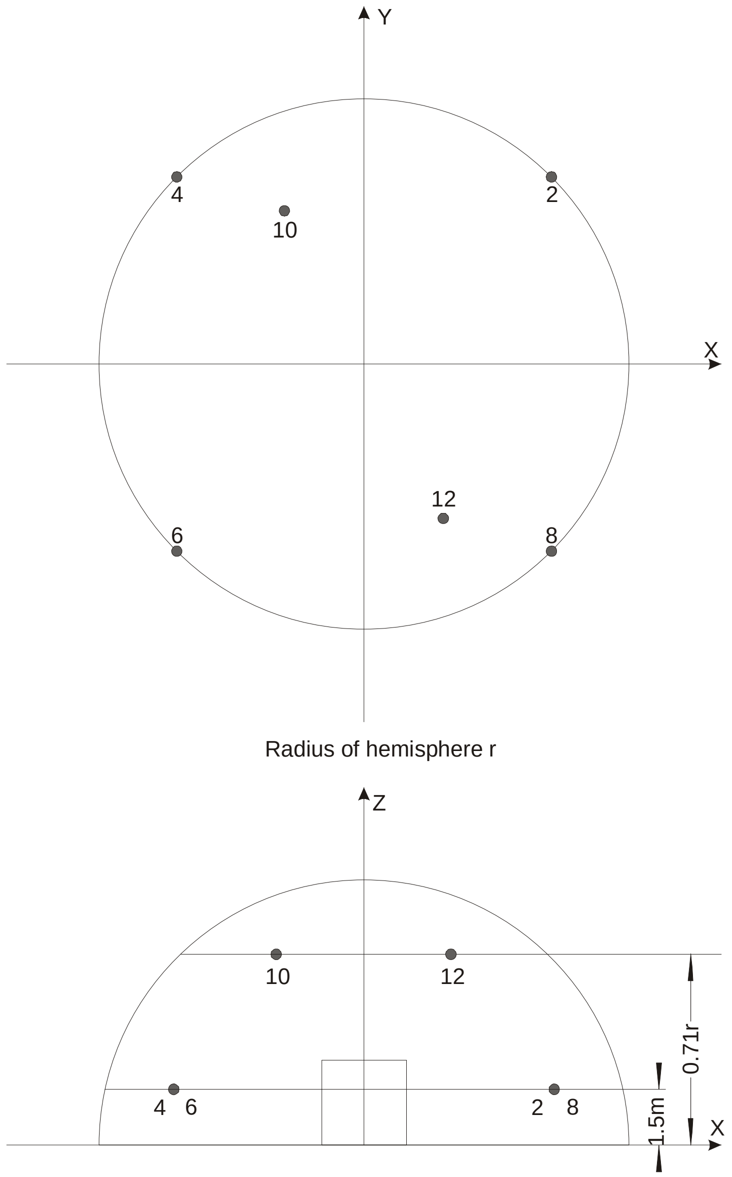

Figure 1: Microphone positions on hemisphere

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.

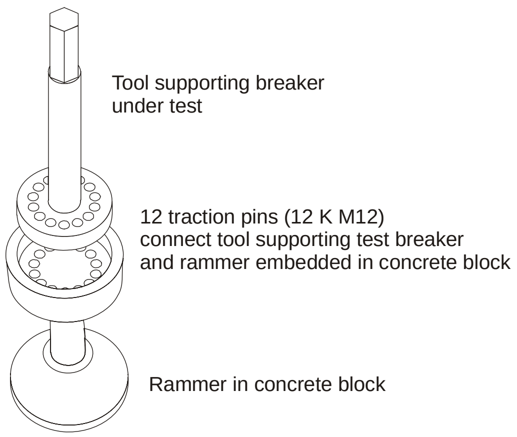

Figure 5: Sketch of intermediate piece

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	-	-	-

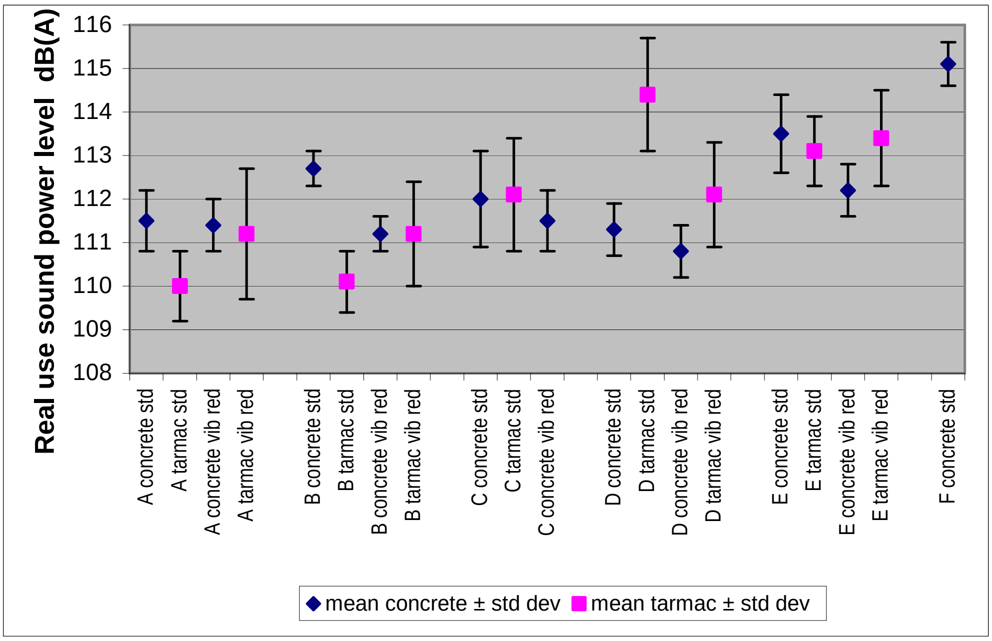

Figure 13a: Simulated real use sound power levels

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	-	-	-

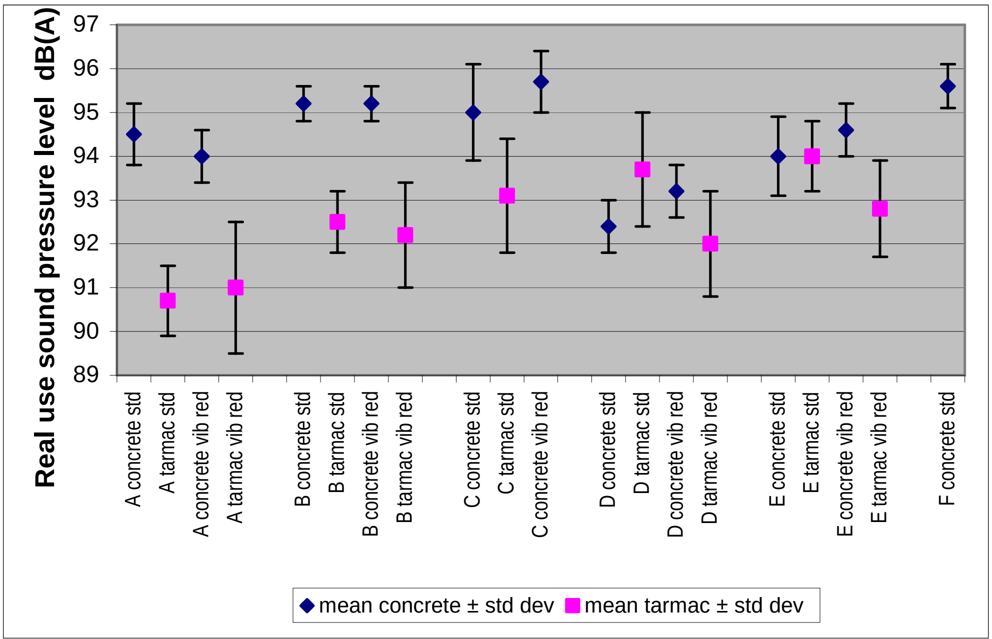

Figure 13b: Simulated real use sound pressure levels

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

5 DISCUSSION

5.1 NOISE EMISSION DATA

5.1.1 Comparison of declared and measured noise emission data

According to BS EN ISO 4871: 1997 [8] and EN 27574-2: 1988 [9], when a single tool is evaluated rather than a batch, the manufacturer's declared emission is verified if the measured noise emission value, L_1 is less than or equal to the declared single-number or dual-number noise emission value. [Note: Although Schedule 10 NEEEOR 2001 describes a procedure for unit verification, it does not include a reference to or describe the method that should be used to verify the declared noise emission value.]

Table 5 shows a comparison of the declared and measured noise emission values for each tool. HSL verified the manufacturer's declared noise emission for only two of the six breakers tested: Tool B and Tool C. Tool B was the only breaker tested that does not have anti-vibration handles. The largest difference between the declared and measured noise emission was for Tool E. During the noise emission tests, we observed that the sleeve of this breaker was spinning around the breaker body. Efforts to tape the sleeve to the body failed. A consequence of the spinning sleeve was that exhaust noise was radiated in all directions, possibly raising the noise level at microphone positions 2, 4, 6, and 10. The other breakers tested radiated exhaust noise in a fixed direction, resulting in raised levels at generally only two of the microphone positions. It is likely there was a fault with Tool E, suggesting that it was not a representative sample for this type of breaker.

5.1.2 Problems with the standard emission test specified in NEEEOR 2001

The manufacturer's declared noise emission values were verified for only two of the six breakers tested by HSL. During construction of the HSL test rig, some problems were identified with the standard test defined in NEEEOR 2001. Omissions and technical difficulties in meeting some of the requirements may result in differences in the measured noise emission data from different test houses. The main difficulties are described briefly below:

- There is no information in the standard NEEEOR 2001 test on how the breaker should be supported during the noise emission tests, including whether or not an operator should operate the tool. The only guidance provided is that "conventional operating conditions for each type of tool shall be laid down that produce effects and stresses similar to those undergone under actual working conditions". Without prior experience of testing breakers, this advice does not provide sufficient information to ensure repeatability of the test data. However, further guidance was obtained from the EU concrete breaker directive 84/537/EEC, which describes various alternative methods for supporting the breakers during the standard noise test. In the absence of any other guidance this should be considered for inclusion in NEEEOR 2001.

- Although the EU concrete breaker directive 84/537/EEC contains useful information on how to support the breakers during the standard test, it lacks details on certain aspects of the test that may influence the measured noise levels. For example, there is no guidance on how much vertical force should be applied to the breaker handles. In the HSL tests, the applied vertical force was taken to be the force required to fix the anti-vibration breaker handles in their mid-position of travel. However sound power levels measured with the breaker handles supported in the mid-position of travel and also fully depressed varied by up to 3 dB for some of the breakers tested. A report by Laboratoire National

D'Essais [11] shows that noise levels may vary within a 5 dB spread depending on the vertical force applied on the breakers. These results suggest that breaker support during the standard test should be investigated further and specified more accurately in NEEEOR.

- It was difficult to construct certain parts of the test rig using the information contained in NEEEOR 2001 without previous experience of the test, in particular the system of reinforcing rods within the concrete block. Advice from experts within HSL and other test houses carrying out the breaker emission tests, suggested that it was very difficult, if not impossible, to reinforce the concrete blocks with untied steel rods using the design illustrated in NEEEOR 2001. Even the structure of the reinforcing rods was unclear from the illustration in Figure 10.2 of NEEEOR 2001; additional information is needed and indeed it is not clear why the rods need to be untied. The concrete blocks constructed with tied rods remained structurally sound throughout the tests; only one block was used in the tests reported here.

- It was similarly difficult to construct the intermediate piece used to connect the breaker to the tool embedded in the concrete block from the information contained in NEEEOR 2001. HSL was able to do this only by using technical drawings supplied by one of the breaker manufacturers. This information should therefore be considered for inclusion in the test code.

- According to the standard test, the concrete block should be insulated against the bottom and sides of the concrete pit with elastic blocks with a cut-off frequency that is less than half the striking rate of the breakers tested. HSL used anti-vibration mounts at the bottom of the concrete pit, which partly satisfied this requirement. However there was insufficient space around the sides of the block to do this. Instead, the sides of the block were isolated from the concrete pit by sliding strips of rubber into the gap between the two. It is therefore recommended that the standard test should contain requirements that are achievable in practice.

- The test method in NEEEOR 2001 contained the following printing errors in Figure 10.3, which makes construction of the rig very difficult:

    - The depth of the concrete lined pit is given as 600 mm; according to the EU concrete breaker directive 84/537/EEC and in order to accommodate the concrete block and screening slab, the depth should be 660 mm;

    - The dimensions for the screening slab are not clearly labelled;

    - The label for dimension A is missing from Figure 10.3.

5.1.3 Permissible sound power levels

One of the requirements of NEEEOR 2001 is that the guaranteed sound power level of equipment does not exceed specified maximum permissible sound power levels. A 2 dB reduction in the maximum permissible sound power levels for breakers was planned from 3 January 2006. However NEEEOR 2001 was amended in 2005 [12] to allow the permissible sound power levels for some types of equipment, including concrete breakers between 15 and 30 kg, to remain at the levels set in 2003. Table 9 shows how the permissible sound power levels are calculated for hand-held concrete-breakers and picks.

Table 9: Equations for calculating permissible sound power levels

Mass of appliance in kg	Permissible sound power level in dB re 1 pW	
	Stage I as from 3 January 2002	Stage II as from 3 January 2006
$m \leq 15$	107	105
$15 < m < 30$	$94 + 11 \log_{10} m$	$92 + 11 \log_{10} m$ [1]
$m \geq 30$	$96 + 11 \log_{10} m$	$94 + 11 \log_{10} m$

[1] For powered hand-held concrete-breakers and picks ($15 < m < 30$) the figures for Stage I shall continue to apply for Stage II (NEEEOR 2005)

Table 10 contains the permissible sound power levels for the breakers tested at HSL and the manufacturer's declared emission. The emission values are compared with the permissible sound power levels: 'Yes' indicates that the emission value is within the permissible sound power level, and 'No' indicates that the emission value exceeds the permissible sound power level.

Table 10: Permissible sound power levels

Tool	Permissible sound power level L_W dB		Declared emission		Measured emission	
	Stage I	Stage II	L_d dB(A)	Is L_d equal to or below L_W (Stage II)	L_1 dB(A)	Is L_1 equal to or below L_W (Stage II)
A	110	110	109	Yes	110	Yes
B	109	109	109	Yes	107	Yes
C	109	109	107	Yes	107	Yes
D	113	111	106	Yes	107	Yes
E	112	110	111	No	114	No
F	109	109	108	Yes	109	Yes

The results in Table 10 show that both the manufacturer's declared emission value and the HSL emission value exceed the permissible sound power level for only one tool, Tool E. The consequence of this is that Tool E should not be placed on the market or put into service according to the requirements of regulation 7 in NEEEOR 2001. However it is possible that there was a fault with Tool E, and the data for this particular sample is therefore not representative for this type of breaker.

5.1.4 Analysis of HSL measured noise emission

In order to be able to compare the measured noise emission data obtained for the six breakers, we first need to establish whether the measured emission values for the different tools are significantly different from each other. One-way analysis of variance (ANOVA) (related) and the Tukey HSD (Honestly Significant Differences) test were carried out on the HSL measured noise emission data to identify the breakers that differed significantly. The ANOVA test shows when there are systematic differences between tools but not where they lie; the Tukey HSD test compares each pair of conditions to see whether their difference is significant.

Table 11 shows the results of the statistical analysis performed on the sound power levels measured during the standard noise emission tests. The null hypothesis was that there was no difference between the noise emission values for the different tools at the 5% level, ie they have the same mean value. [Note: 'S' indicates a significant difference and 'NS' indicates that the difference is not significant at the 5% level.]

Table 11: Results of statistical tests carried out on measured emission data

Difference of means	Tool B	Tool C	Tool D	Tool E	Tool F
Tool A	**S**	**S**	**S**	**S**	**S**
Tool B		NS	NS	**S**	**S**
Tool C			NS	**S**	**S**
Tool D				**S**	**S**
Tool E					**S**

The results show that Tools B, C and D were not significantly different and should therefore be given the same rank.

5.1.5 Use of emission data to identify high noise and low noise breakers

Table 12 shows the results of ranking the breakers based on their emission values; 1 indicates the quietest breaker and 6 the noisiest breaker.

Table 12: Ranking of breakers based on declared and measured noise emission

Tool	Declared emission	Declared emission rank	Measured emission	Measured emission rank
A	109	4.5	110	5
B	109	4.5	107	2
C	107	2	107	2
D	106	1	107	2
E	111	6	114	6
F	108	3	109	4

The Spearman r_s correlation coefficient was calculated from the ranked data in Table 12 to investigate the relationship between the declared and measured noise emission data. The value of r_s was 0.76. At the 5% significance level, the correlation was not significant. However, with a small number of tools a high value of r_s is needed for significance. The comparison showed that the declared and measured emission values do not rank the tools in exactly the same order, but they did both identify Tool D as one of the quietest breakers and Tool E as the noisiest breaker.

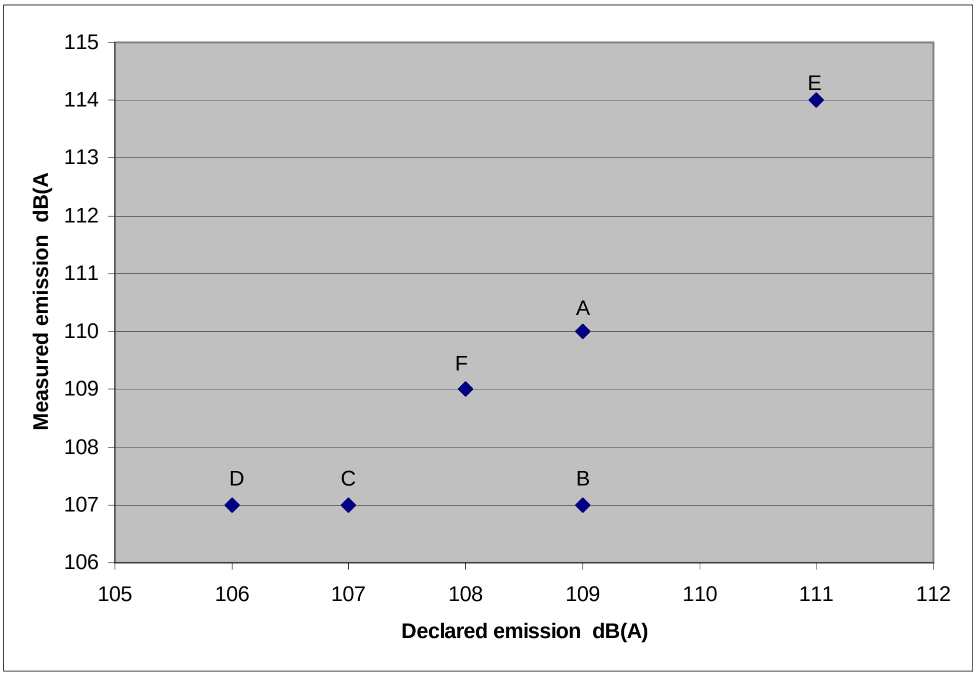

Figure 14: Declared noise emission data plotted against measured noise emission data

The declared and measured noise emission data is plotted in Figure 14. The graph shows that in general, as the declared emission increases, the measured emission also increases. The declared and measured emission data appear to correlate, apart from Tool B. The Spearman r_s correlation coefficient was recalculated for the data in Table 12 excluding Tool B and resulted in an r_s value of 0.975. At the 5% level the correlation between the two sets of data was significant. This shows that for breakers fitted with anti-vibration handles, the standard test produces noise emission data that is reproducible. The results for Tool B suggest further work is needed to investigate the method used to obtain noise emission data for tools with fixed handles.

All the breakers tested were fitted with silencers that enclosed the main body of the tool. According to one tool manufacturer most silencers share the same design although there may be differences in the quality of the materials used to make the silencer. The information provided with the breakers contained no details of design features intended to reduce tool noise. The manufacturer of Tool D described using a tappet bush, through which the piston travels, to reduce the impact on the tappet. The manufacturer has found the tappet bush to be effective at reducing noise and has a long life.

5.1.6 Frequency analysis of standard emission data

Figure 15a shows unweighted frequency spectra for the noise generated by the breakers during the emission tests at HSL; Figure 15b shows the A-weighted frequency spectra. The spectrum for each tool was obtained by averaging the sound pressure levels measured at the six microphones located around the breaker during the tests. These figures show that the breakers generated broadband noise, but high frequencies dominated the A-weighted levels reported here.

The spectra in Figures 15a and 15b show that Tool E generated the highest sound pressure levels across the frequency range 31.5 Hz to 10 kHz; Tool D generated the lowest sound pressure levels between 31.5 Hz and 3.15 kHz. Above 4 kHz, Tools B, C and F generated the lowest sound pressure levels; these were the lightest of the breakers tested.

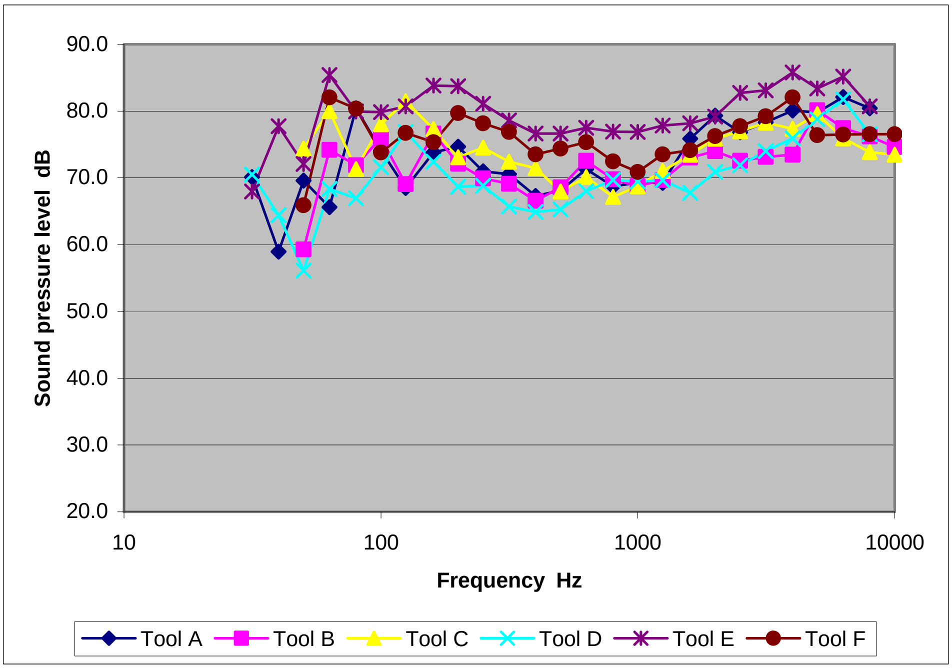

Figure 15a: Unweighted mean frequency spectra during standard tests

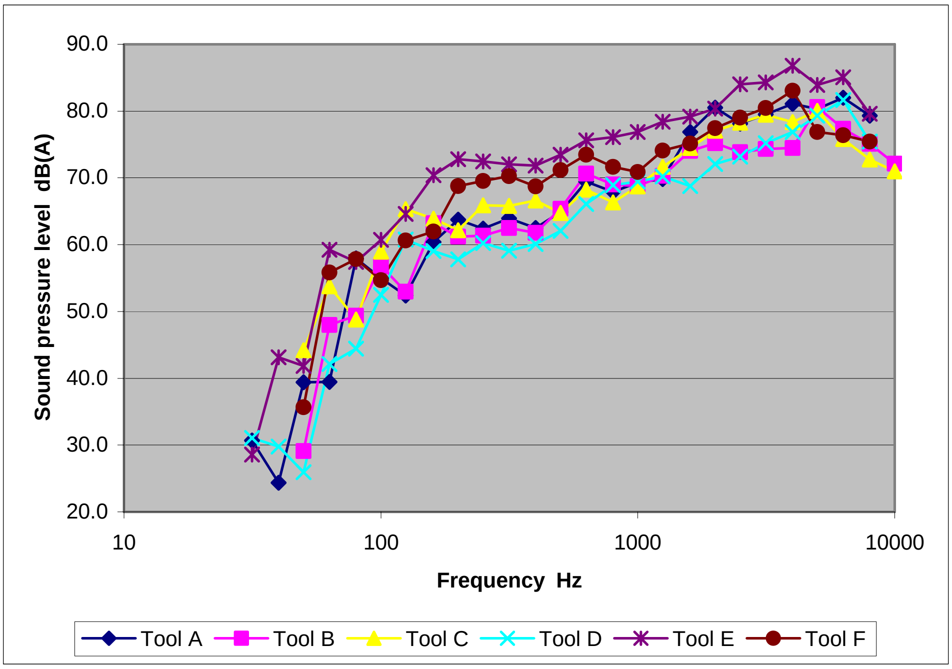

Figure 15b: A-weighted mean frequency spectra during standard tests

Sound pressure levels measured for each breaker at the six measurement positions during the emission tests are shown in Figures 16a to 16f. The impact frequency of the breakers tested was between 16 and 23 Hz. Harmonics associated with these frequencies were observed at low frequencies at all measurement positions for all the tools.

For all tools, except Tool F, the highest sound pressure levels were measured at the microphones positioned closest to the breaker exhaust. For Tools A, B, D and E these were the microphones at positions 4 and 6; for Tool C these were the microphones at positions 6 and 8. This suggests that exhaust noise was a significant source of tool noise during the emission tests. Although Tool F was exhausted between microphone positions 6 and 8, higher sound pressure levels were measured at microphone positions 2 and 4. Higher sound pressure levels were measured at microphone positions 10 and 12 between 630 Hz and 1 kHz for all the tools except Tool F; these microphones were closer to the breaker but positioned 2.84 m above the ground.

The frequency spectra for Tool F suggested that this tool radiates sound in a different way to the other tools. The highest noise levels were measured at the microphones positioned farthest from the tool's exhaust. Tool F was the lightest breaker tested, and it was the only breaker with a 25 hex x 108 mm chuck size, which meant that it was connected to the test rig using a different intermediate piece from the other tools. It is not clear why the radiation of noise from this tool was different from other tools. Additional work would therefore be needed to investigate this further.

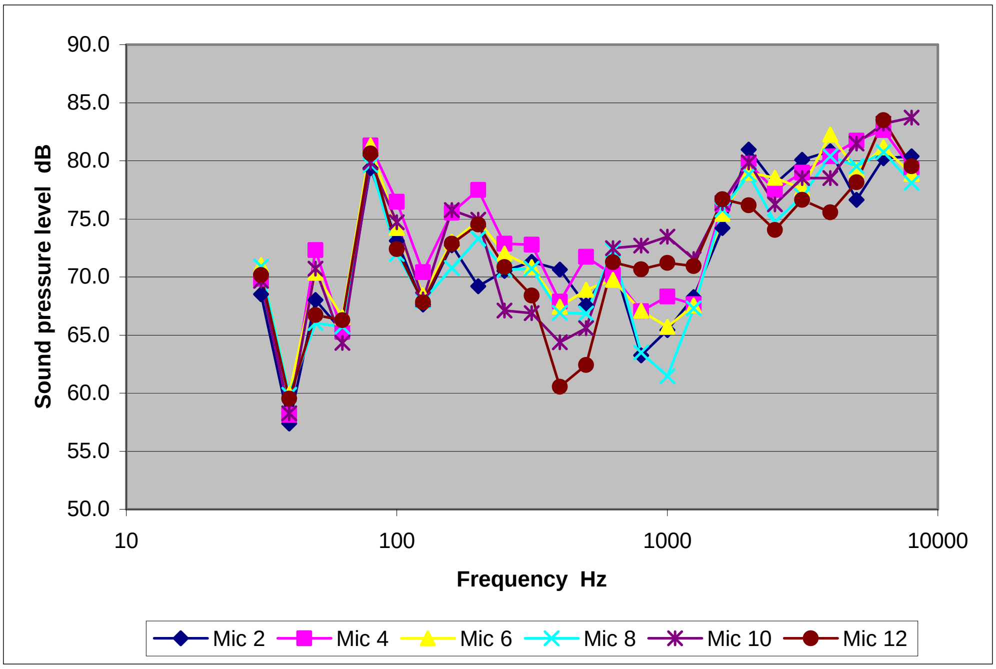

Figure 16a: Tool A

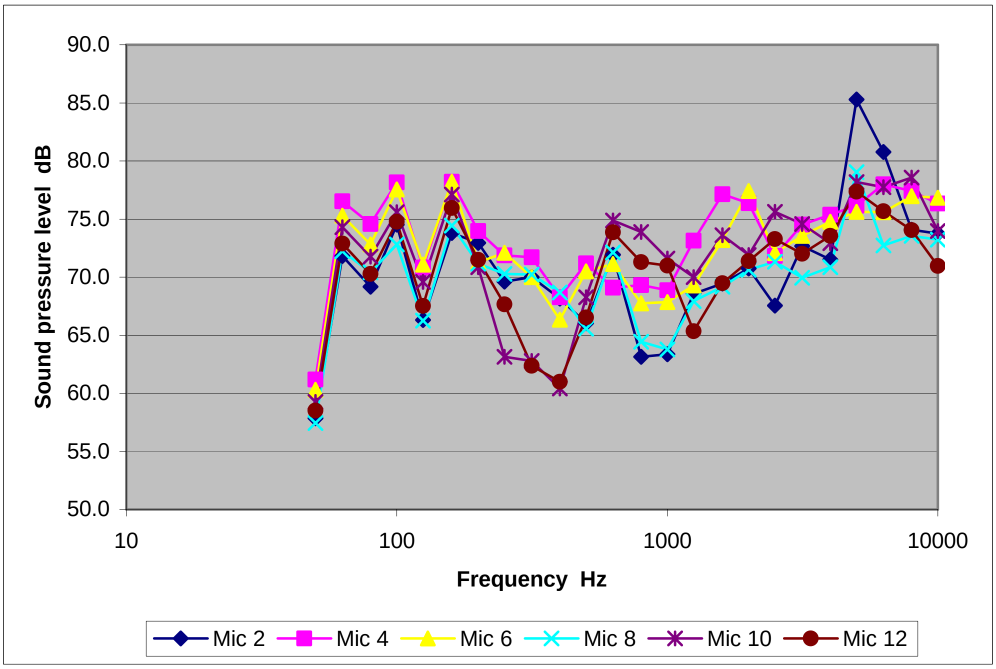

Figure 16b: Tool B

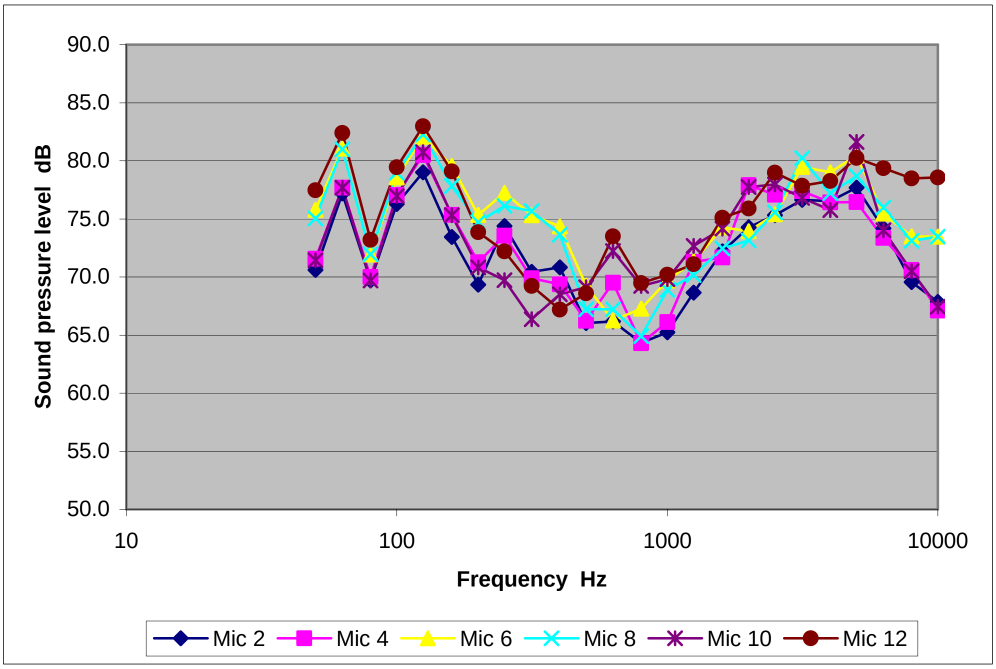

Figure 16c: Tool C

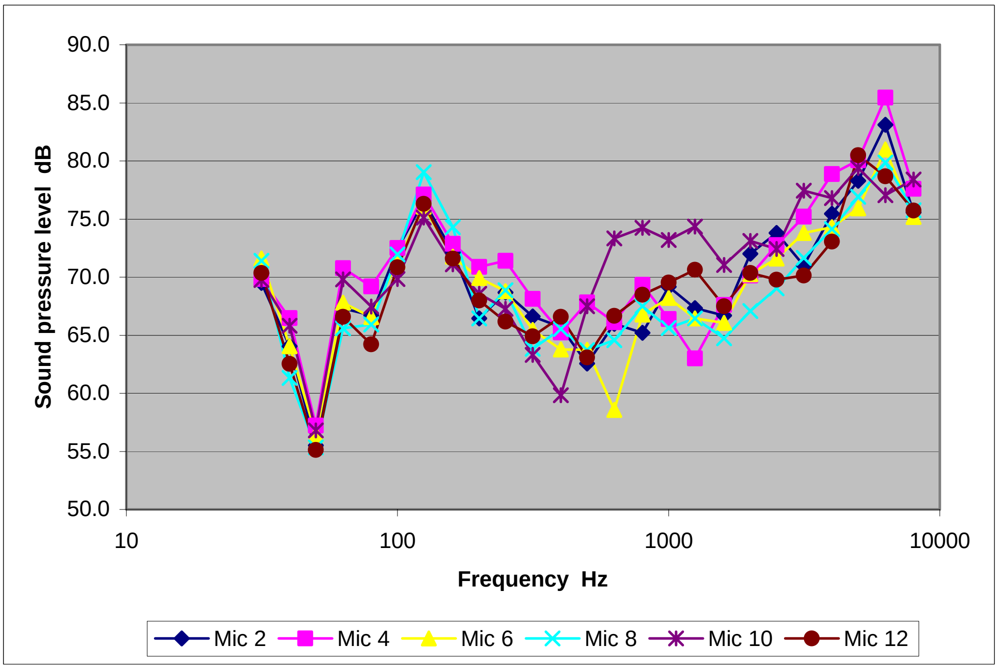

Figure 16d: Tool D

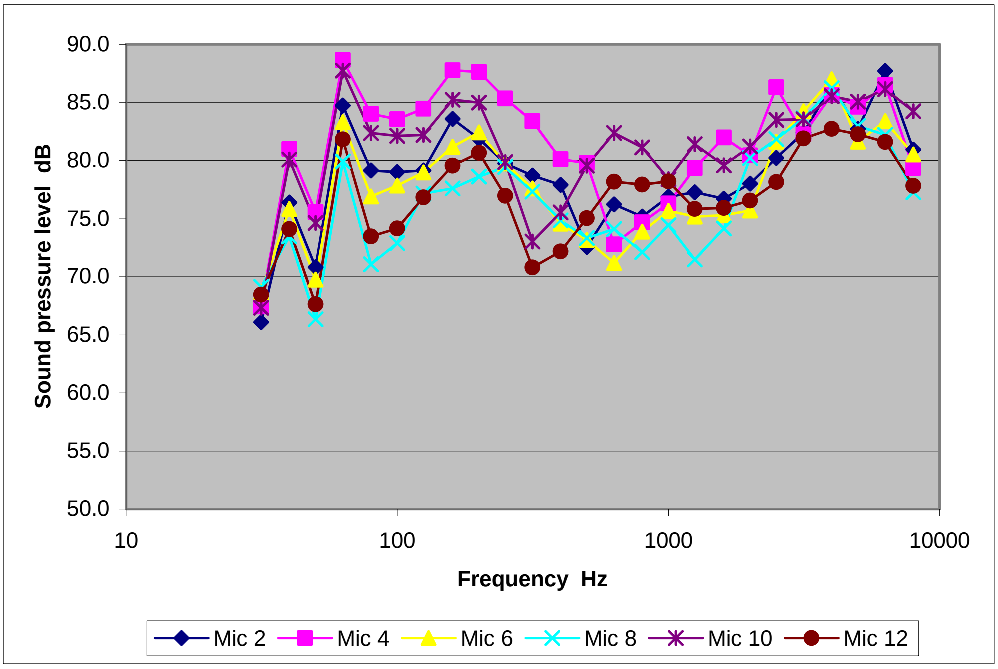

Figure 16e: Tool E

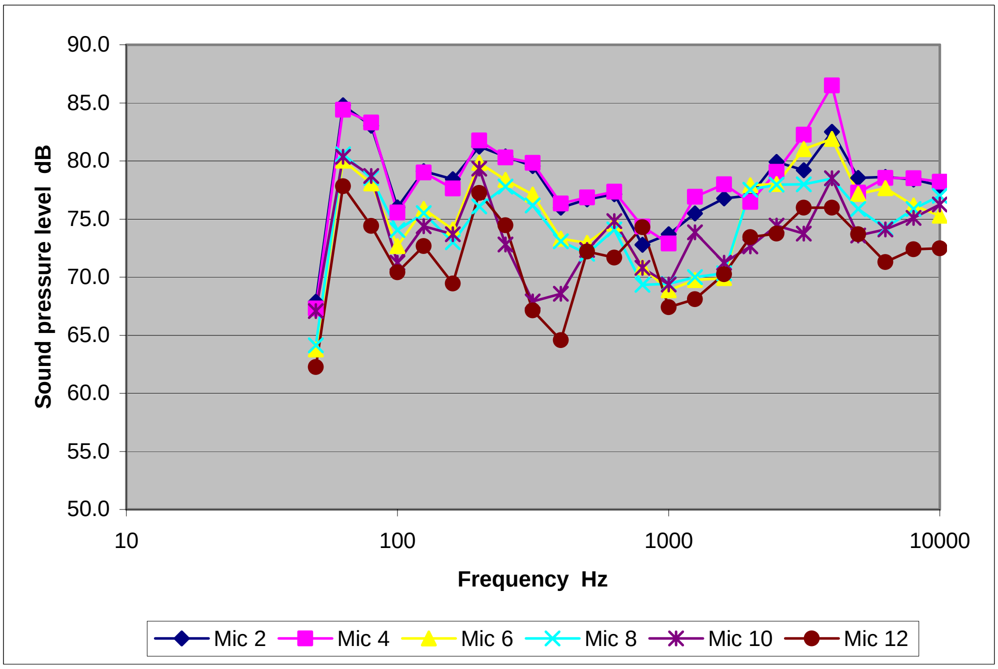

Figure 16f: Tool F

5.2 SIMULATED REAL USE NOISE DATA

The simulated real use test on tarmac involved working an open face by cutting along the tarmac surface to break it up. This task is typical of how the breaker is used in practice. The test on concrete was less realistic; it 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. In practice, the breaker would be used to create an open-face which allows the broken-up material to fall away. The operator is less likely to bury the breaker steel in the material using this method. When the breaker becomes embedded in the material, dust and rubble are created around the steel, which can cause the steel to heat up.

One operator used Tool A and Tool B to break up a concrete edge, which is a more realistic operation. A sound level meter was used to measure the sound pressure levels at the operator's ear during these tests. The noise levels generated during this more realistic task were up to 3 dB higher than those generated at the operator's ear during the simulated real use test. It is likely that the breakers will generate a range of different noise levels during normal use depending on many factors including the task, method of operation and type of surface. The purpose of the simulated real use tests reported here is to give an indication of the effect of surface type and steel type on different breakers under controlled conditions.

5.2.1 Effect of different surfaces

The breakers were tested on two different surfaces: concrete and tarmac. Figures 13a and 13b show the mean and standard deviation of simulated real use sound power levels and sound pressure levels. The test results presented here do not show a clear relationship between surface type and the noise levels generated. For example, Tools A and B generated higher sound pressure levels and higher sound power levels when used to break up concrete compared to tarmac. By comparison, Tool D produced higher levels breaking tarmac.

The differences between the results obtained on concrete and on tarmac were normally distributed. Therefore the related t test was performed on the data to investigate whether the observed differences were significant. A summary of the results is contained in Table 13. [Note: 'S' indicates a significant difference and 'NS' indicates that the difference is not significant at the 5% level.]

Table 13: Results of statistical tests to investigate the effect of surface type on breaker noise

Tool	Sound power level		Sound pressure level	
	Standard steel	Vibration reduced steel	Standard steel	Vibration reduced steel
A	S	NS	NS	NS
B	S	NS	S	NS
C	NS	-	NS	-
D	S	NS	NS	NS
E	NS	S	NS	NS

At the 5% level, the sound power levels for Tools A and B fitted with standard steels were significantly higher on concrete compared to tarmac; for Tool D fitted with a standard steel the sound power level was significantly lower on concrete compared to tarmac. For Tool B fitted with a standard steel, the sound pressure levels at the operator's ear were significantly higher (at the 5% level) on concrete compared to tarmac. The results suggest that the lighter tools (A and B) generated higher noise levels on concrete, and heavier tools generated higher levels on tarmac. Therefore in normal use choosing a heavier tool for concrete and a lighter tool for tarmac is likely to result in lower noise levels at the operator's ear. However it is important to note that the statistical tests were performed on small sample sizes, and any conclusions should be treated with caution. The sample size used here was in accordance with the standard test procedure, which requires that surface sound pressure levels are determined at least three times. It is interesting to note that a guide for manufacturers on evaluating uncertainties when carrying out tests for Directive 2000/14/EC [13] recommends a sample size of five. According to this guidance, a minimum of five repeat measurements or five machines will ensure that the uncertainty associated with measurement and production uncertainties is representative of the true value. It is not clear why this guidance differs from the recommended number of repeats required by NEEEOR 2001.

5.2.2 Effect of different steels

Figures 17a and 17b show comparisons of the sound power levels obtained for standard steels and vibration reduced steels; Figures 18a and 18b show the effect of the different steels on the sound pressure levels measured at the operator's ear. These figures show several different trends: the vibration reduced steels generally reduced sound power levels on concrete (except for Tool A) and sound pressure levels on tarmac (except for Tool A); and increased sound power levels on tarmac (except for Tool D) and sound pressure levels on concrete (except for Tool A). There was no data available for Tool C on tarmac. The locking mechanism on this breaker malfunctioned when used with the vibration reduced cutter, which resulted in the tool being released during operation. This was a safety hazard and these tests were therefore abandoned.

The differences between results obtained for the standard and vibration reduced steels were normally distributed. Therefore the related t test was performed on the data to investigate whether the observed differences were significant. A summary of the results is contained in Table 14. [Note: 'S' indicates a significant difference and 'NS' indicates that the difference is not significant at the 5% level.]

Table 14: Results of statistical tests to investigate the effect of standard and vibration reduced steels on breaker noise

Tool	Sound power level		Sound pressure level	
	Concrete	**Tarmac**	**Concrete**	**Tarmac**
A	NS	S*	NS	NS
B	S**	NS	NS	NS
C	NS	-	NS	-
D	NS	S**	S*	NS
E	S**	NS	S*	NS

* Vibration reduced steel increased noise levels
** Vibration reduced steel reduced noise levels

At the 5% level, the vibration reduced steel significantly reduced the sound power levels for Tools B and E on concrete and Tool D on tarmac, compared to the standard steels. However the statistical tests also showed that using the vibration reduced steels could significantly increase the measured noise levels: higher sound power levels were observed for Tool A on tarmac, and higher sound pressure levels were measured for Tools D and E on concrete. The results suggest that vibration reduced steels can make a significant difference when used with heavier tools. However there is insufficient data to explain why the vibration reduced steels appear to reduce the sound power levels but increase the sound pressure levels, and also why they have different effects when used on different surfaces.

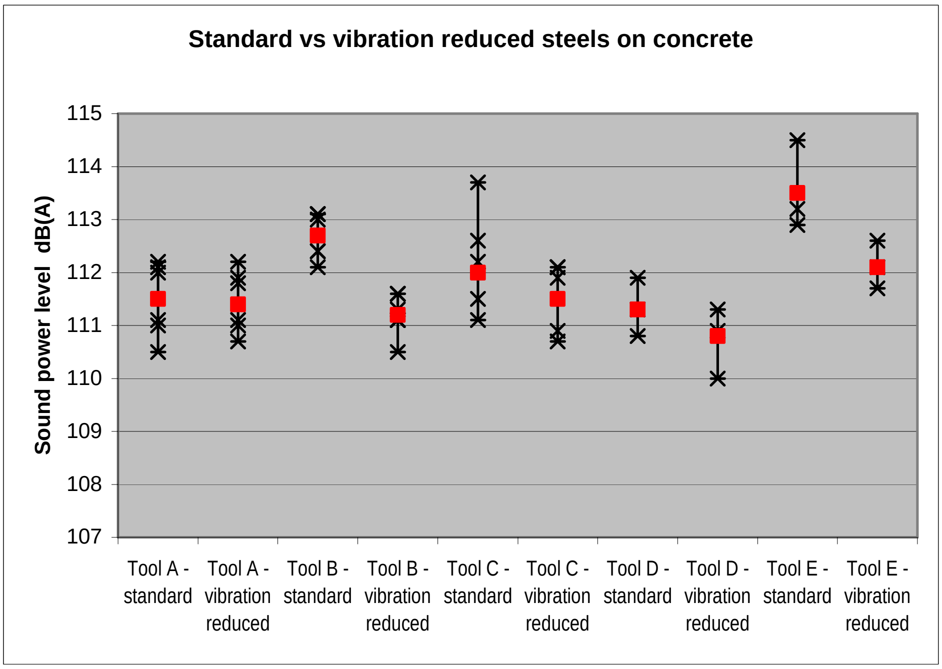

Figure 17a: Comparison of normal use sound power levels on concrete

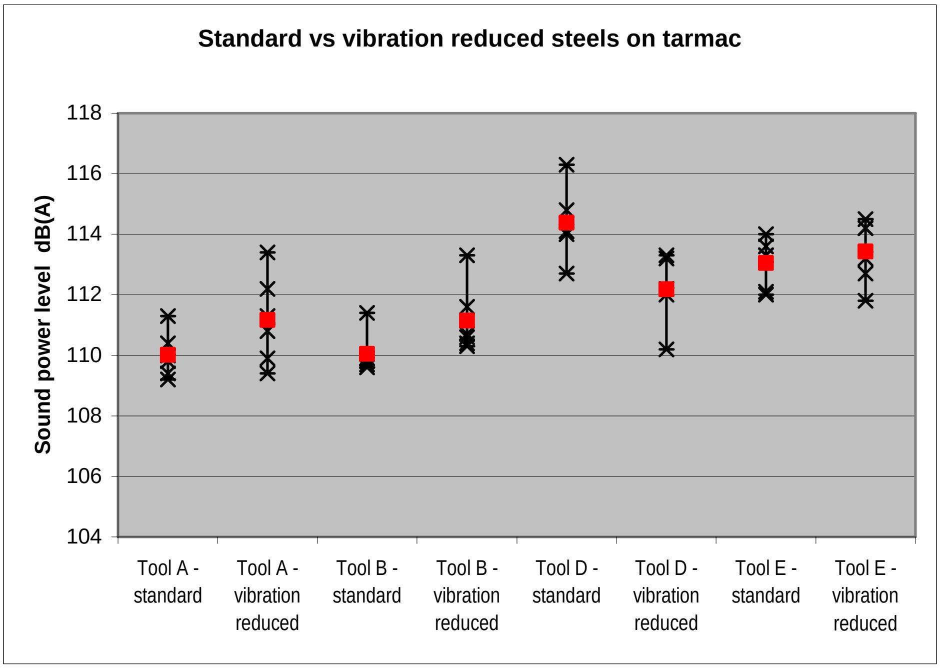

Figure 17b: Comparison of normal use sound power levels on tarmac

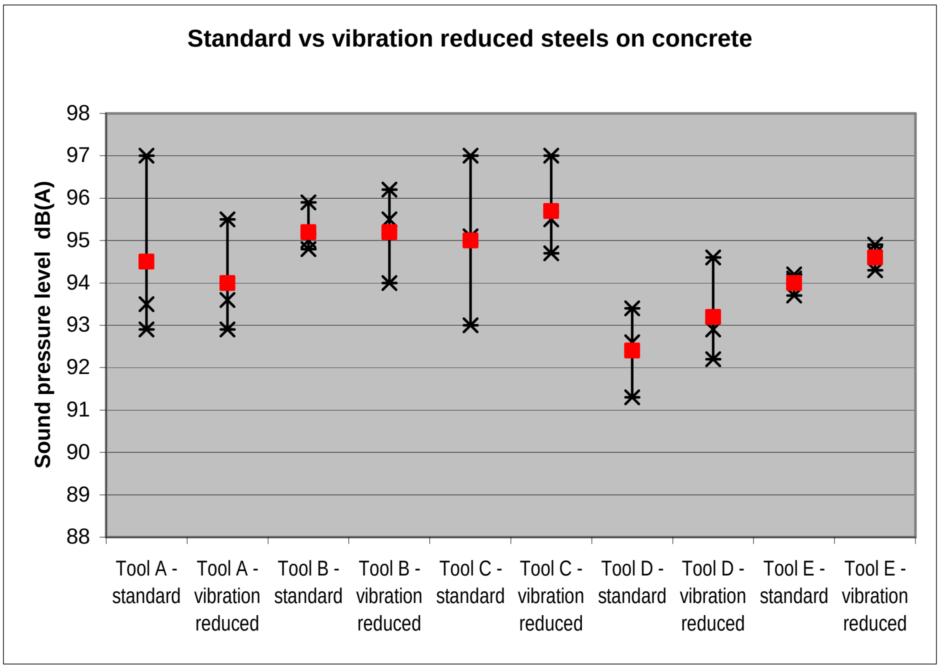

Figure 18a: Comparison of normal use sound pressure levels on concrete

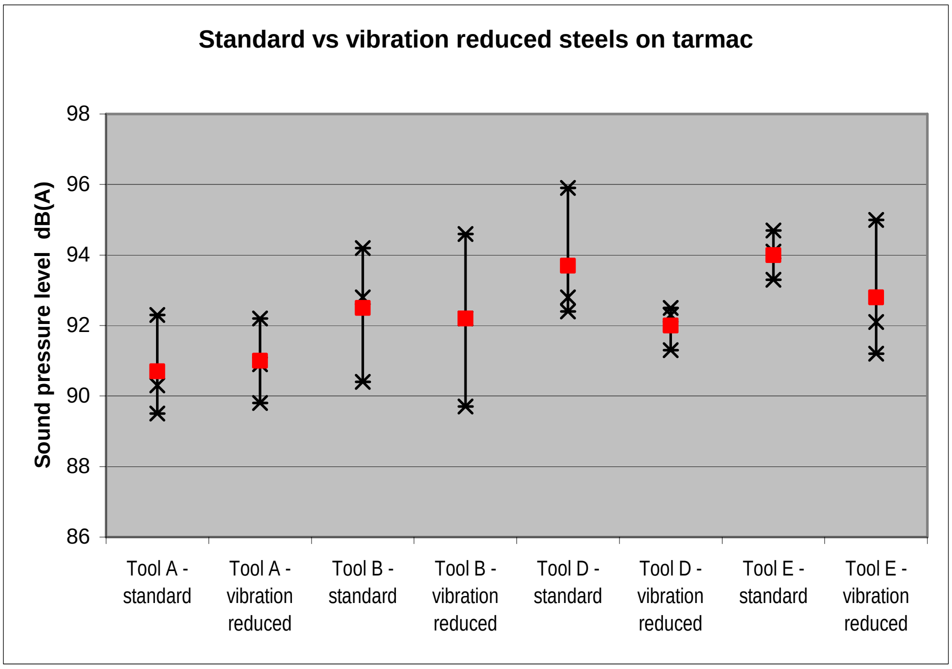

Figure 18b: Comparison of normal use sound pressure levels on tarmac

5.2.3 Tool productivity

An attempt was made to assess the productivity of each breaker during the simulated real tests. The break-outs made by each of the three operators during the 20 s measurement period were summed to give the total number of break-outs for each breaker on concrete. Similarly the passes made by each operator were summed to give the total number of passes for each breaker on tarmac. These summed values are shown in Table 15 for breakers with standard and vibration reduced steels.

Table 15: Total number of break-outs and passes made during simulated breaking

Tool	Total number of break-outs (concrete)		Total number of passes (tarmac)	
	Standard moil	Vibration reduced moil	Standard cutter	Vibration reduced cutter
A	8	10	21	18
B	11	7	15	20
C	8	8	15	-
D	11	11	15	16
E	10	10	20	16
F	13	-	-	-

There were no significant differences between the number of break-outs or passes created during the simulated real use breaker tests for either the different tools or the different steels. There was very little difference between the number of break-outs on concrete for different operators, breakers and steels; the number of break-outs per 20 s measurement period ranged from 2 to 4. The tests on tarmac generated more variation and the number of passes for each 20 s measurement period was between 4 and 8. The results suggested operator technique and surface variability might have influenced this productivity measure on tarmac.

A questionnaire was administered to the operators following each breaker test to collect subjective information on productivity, comfort and ease of use [10]. The comments made by the operators showed that they did not like Tool C; they reported that this breaker "bounced around" on the surface and was unproductive. The number of break-outs and passes obtained using Tool C supported this subjective assessment. The operators preferred Tool E because it had good handles, was the right weight and was productive. It is not obvious from the objective data reported in Table 15 that Tool E would be preferred over other breakers in terms of its productivity, especially on concrete. When asked to comment on whether the vibration reduced steels affected productivity, the operators' comments were inconclusive and dependent on the surface being broken.

The simple methods used to assess productivity have not identified any significant differences between the different breakers, nor between the different types of 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.

5.2.4 Effect of other tool characteristics

Statistical tests applied to the simulated real use sound power levels and sound pressure levels did not identify any significant relationships between the measured noise levels and other tool characteristics, including tool mass, air consumption and impact frequency.

5.2.5 Frequency analysis of simulated real use data

The unweighted mean frequency spectra generated by Tool D during the simulated real use tests are shown in Figure 19. These mean frequency spectra were obtained by averaging the sound pressure levels measured at the six microphone positions during normal use tests. The data for this tool were chosen at random to show typical normal use frequency spectra for different surfaces and different steels. For comparison, a typical frequency spectrum for Tool D obtained during the standard emission test is also shown in Figure 19.

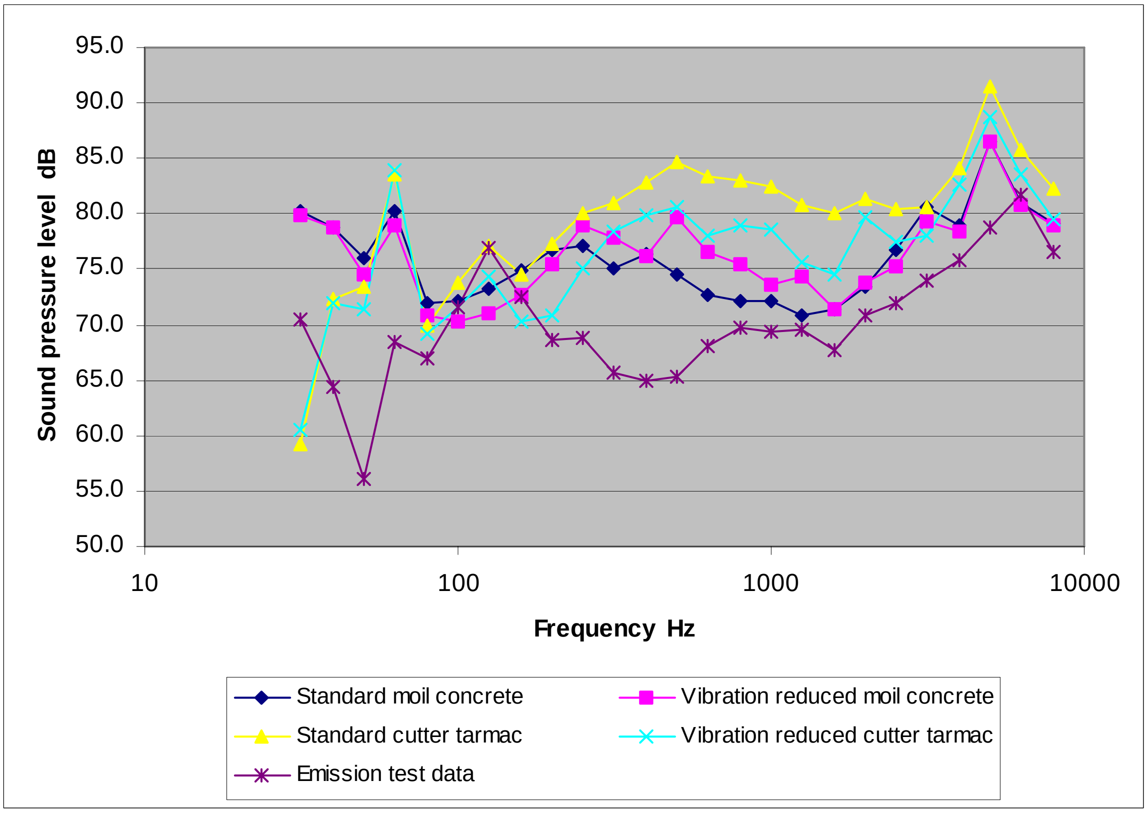

Figure 19: Frequency spectra for Tool D during simulated real use tests

The impact frequency for Tool D is 16 Hz. Harmonics associated with this impact frequency are shown in Figure 19. The spectra show that between 315 Hz and 8 kHz, higher levels were generated when the tool was used to break the tarmac surface as compared to the concrete surface. For both surfaces and both steels, the maximum sound pressure level occurred in the one-third octave band centred at 5 kHz. Figure 19 shows that during the standard emission tests, the maximum sound pressure level occurred at 6.3 kHz. It is not clear why this frequency shift occurred. Figure 19 also shows that the sound pressure levels generated during the emission test were lower than the simulated real use sound pressure levels at all frequencies above 200 Hz.

5.3 COMPARISON OF EMISSION AND SIMULATED REAL USE DATA

Measured noise emission values and simulated real use sound power levels and sound pressure levels for each breaker are shown in Figure 20. The mean simulated real use sound power levels are shown by the yellow triangle, the mean simulated sound pressure levels by the red circle; the error bars indicate the standard deviations, which were less than 2 dB for all of the breakers tested.

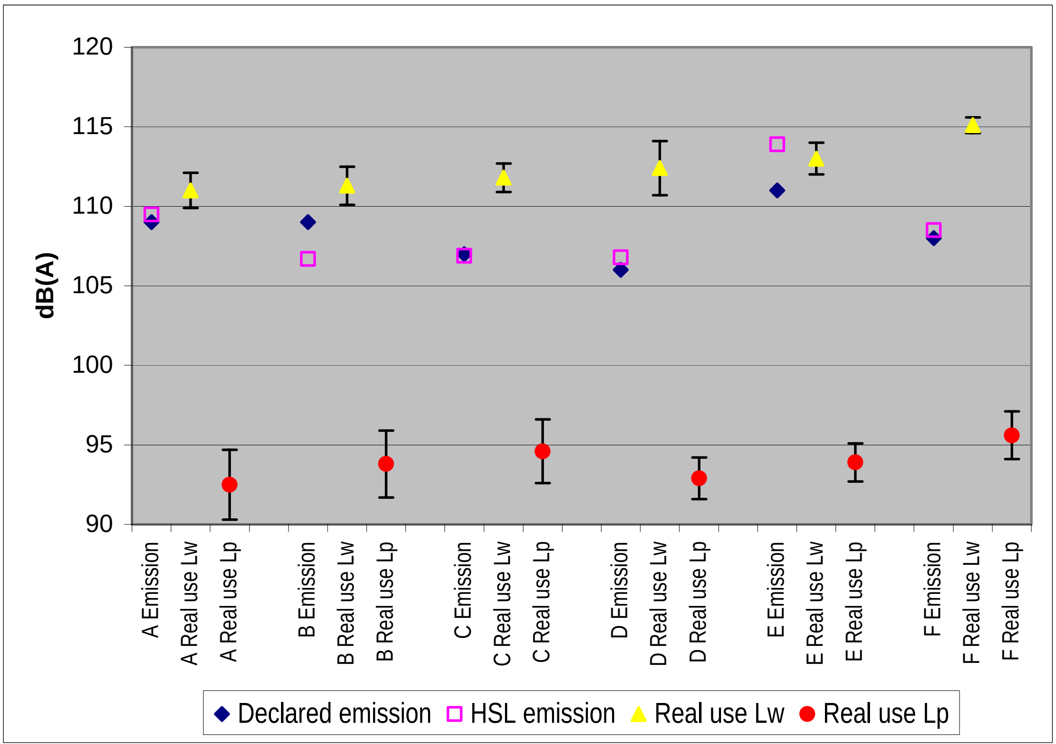

Figure 20: Emission and mean simulated real use noise levels

NB: Lw denotes sound power level; Lp denotes sound pressure level

The mean simulated real use sound power levels were between 2 and 7 dB higher than the measured noise emission values, excluding Tool E; the mean difference was 5 dB. For Tool E the measured noise emission value was 1 dB higher than the normal use sound power level.

Figure 21a shows the simulated real use sound power levels plotted against the HSL measured emission values, Figure 21b shows the simulated real use sound pressure levels plotted against the HSL measured emission values. If the measured noise emission value was a good indicator of the noise levels during normal use then the data for each tool would sit on a linear trend line, which intercepted the x and y axes at zero. The data shown in Figures 21a and 21b does not do this, indicating that the measured emission values and the real use values do not correlate.

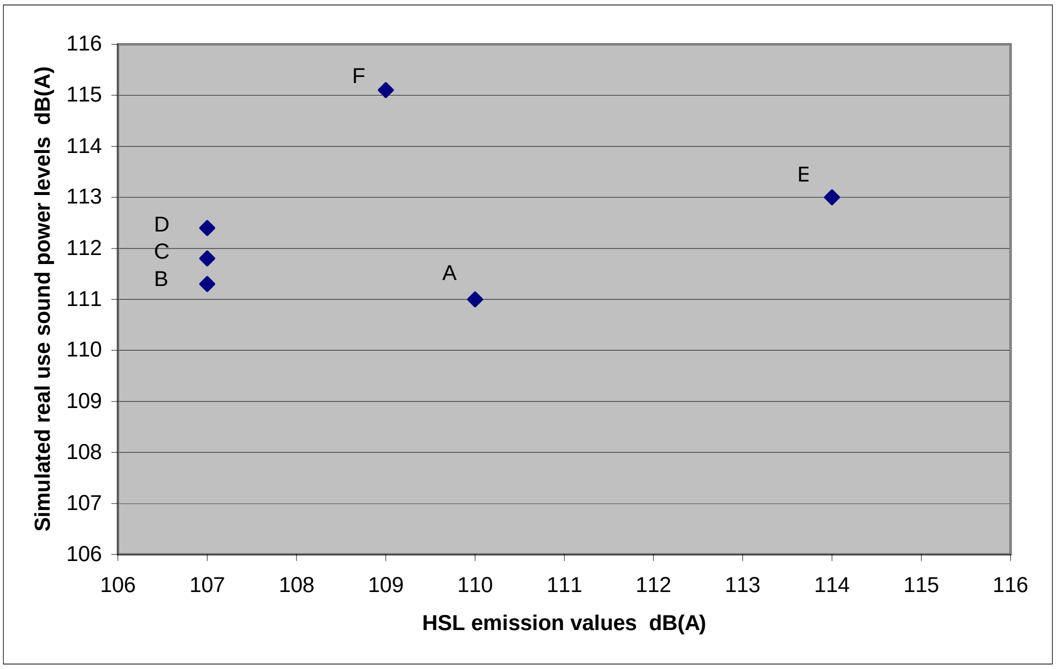

Figure 21a: Simulated real use sound power levels

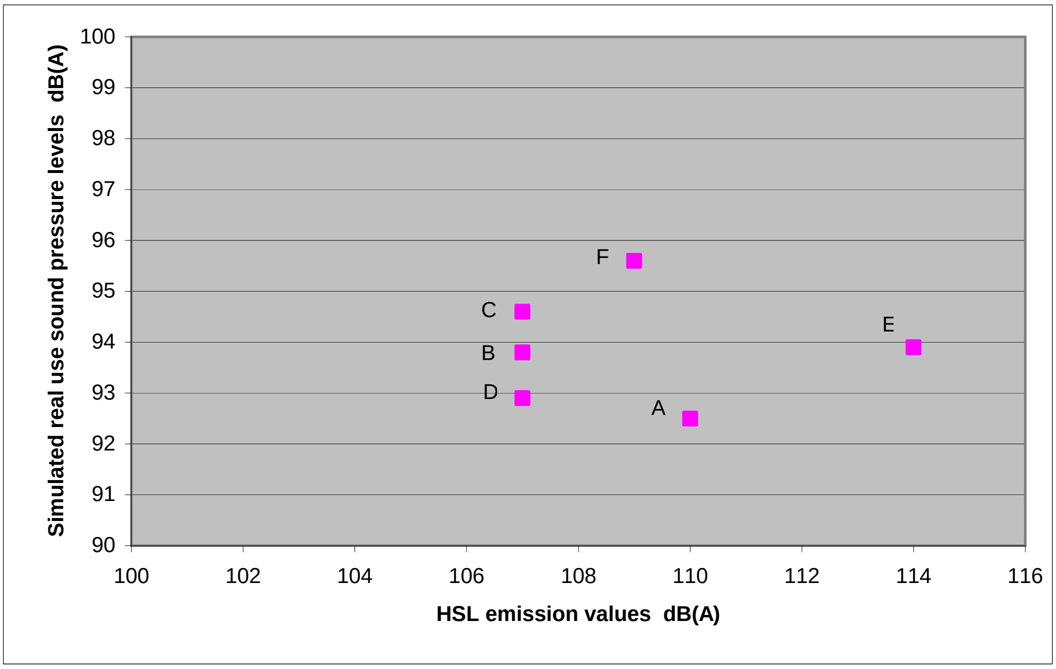

Figure 21b: Simulated real use sound pressure levels

One-way analysis of variance (ANOVA) (related) and the Tukey HSD test were applied to the simulated real use sound power levels and sound pressure levels to establish whether the tools differed significantly in terms of the noise they generated during normal use. Tool F was excluded from this analysis because insufficient noise data was obtained for this breaker during the simulated real tests. Statistical analysis showed that at the 5% level there was no significant difference between the sound pressure levels or the sound power levels generated by the different breakers during simulated real use.

The Pearson Moment Correlation Coefficient r was calculated to investigate the relationship between the measured noise emission values and the simulated real use sound power levels and sound pressure levels. This statistical analysis showed that there was no significant correlation between the measured noise emission values and the simulated real use sound power levels and sound pressure levels for the breakers. This result was expected since there was no significant difference between the noise levels generated by the different breakers during simulated real use.

The results presented here show that although the standard test produces noise emission data that is reproducible, it cannot indicate the relative noise hazard associated with different tools during normal use because the noise levels they generate are not significantly different. The results also suggest that there is no significant difference between the noise generated by breakers with fixed and anti-vibration handles during normal use. However because only one tool with fixed handles was included in these tests, additional work is recommended to investigate this further.

One of the aims of the work reported here was to investigate whether emission data can be used to assess noise exposure of breakers during normal use. To do this, the difference between the measured emission value and the mean simulated real use noise level was calculated for each breaker. Two sets of data are shown in Figure 22:

- The blue diamonds represent the difference between the HSL measured noise emission values and the sound power levels generated during simulated real use tests.

- The pink squares represent the difference between the sound pressure levels at the operator's ear measured during standard emission tests and during simulated real use tests.

If the measured emission and simulated real use noise values were the same, the difference between the two values would be zero. Points below the zero line indicate that the emission values underestimate the normal use noise levels. Points above the line indicate that the emission values overestimate the normal use noise levels.

Figure 22 shows that the measured noise emission values underestimated the sound power levels generated during simulated real use tests for Tools A, B, C, D and F. It is likely that this occurred due to the additional noise generated by interaction of the steel and the surface during the breaking process. The sound pressure levels measured at the operator's position during the standard tests were either comparable with or overestimated the sound pressure levels generated during simulated real use tests for all the breakers except Tool F. The sound power level takes account of the noise radiated from the breaker in all directions. In practice the sound pressure level measured at the operator's ear will depend on many factors including the directivity of the breaker noise and the position of the operator, for example relative to the breaker exhaust.

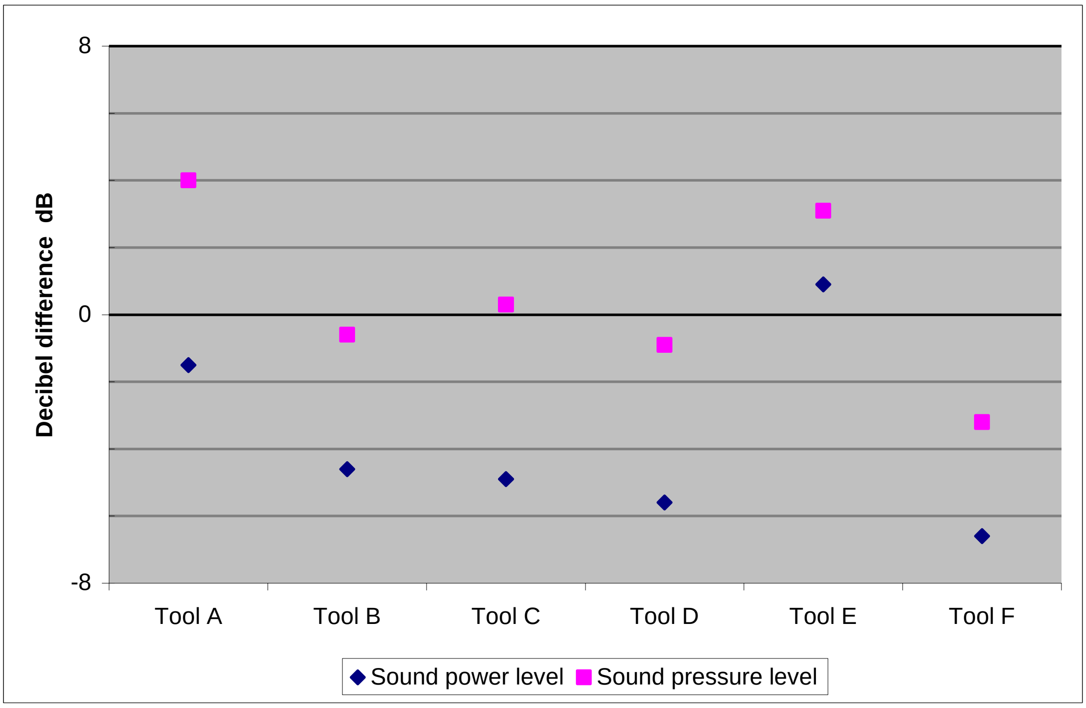

Figure 22: Difference between measured emission values and simulated real use noise levels

6 CONCLUSIONS

- Manufacturers' declared emission values obtained using the standard test method defined in NEEEOR 2001 were only verified according to the criteria in BS EN ISO 4871 for two of the six breakers tested.

- HSL constructed the test rig in accordance with the requirements of NEEEOR 2001. However it was difficult, and in some cases impossible, to comply with all of the requirements because of omissions and technical difficulties with the specified standard test. It is possible that these difficulties resulted in differences between the declared and measured noise emission data.

- We recommend that the DTI is informed of the problems identified with the test method 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.

- The manufacturers' declared emission and the HSL measured emission did not exceed the maximum permissible sound power levels specified in NEEEOR 2005 for five of the six tools tested.

- The standard test method gave reproducible results for breakers with anti-vibration handles. Further work is recommended for investigating the use of the NEEEOR 2001 test method with breakers with fixed handles.

- There was no significant difference between the sound pressure levels or the sound power levels generated by the different breakers during simulated real use tests. The mean sound pressure levels were between 92 and 95 dB(A), the mean sound power levels were between 111 and 113 dB(A). [Note: Tool F was excluded from this analysis because there was insufficient normal use data; it was also the only tool with a smaller shank size 25 hex x 108 mm.]

- The measured emission values did not differentiate the relative noise hazard associated with each of the individual breakers during normal use, because during simulated real use tests the breakers generated largely similar noise levels (sound pressure levels and sound power levels).

- In general, the measured emission data underestimated normal use sound power levels. It is likely this is due to the noise generated during the breaking process (ie interaction of steel and surface) which dominates real use sound power levels.

- In general, the sound pressure levels measured at the operator's position during the emission tests were either comparable with, or greater than, the normal use sound pressure levels. It is possible this was due to the directivity of the breaker noise and the position of the operator, for example relative to the breaker exhaust.

- Analysis suggested that exhaust noise was a significant source of tool noise during emission tests. Although during simulated real use tests, the results suggested that process noise (ie interaction of steel and surface) dominated the noise generated by the majority of the breakers.

- Manufacturer's information supplied with the breakers contained no details of design features intended to reduce tool noise. All 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 uses a tappet bush, which the manufacturer claims is effective at reducing noise and has a long life. It is not clear whether this feature is unique in breaker design.

- In some cases 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. Additional work is required to investigate the effect of vibration reduced steels on breaker noise further.

- The simple methods used to assess the productivity did not identify any significant differences between the different breakers, nor between the different types of 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).

7 REFERENCES

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[3] Noise Emission in the Environment for use Outdoors Directive 2000/14/EC

[4] Noise Emission in the Environment for use Outdoors Regulations 2001, Statutory Instrument No. 1701

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[6] Permissible sound power level of powered hand-held concrete-breakers and picks Directive 84/537/EEC

[7] Hewitt S, Shanks E, Heaton R and Mole M L (2006), "Vibration emission and simulated real use measurements on six road breakers", HSL Report NV/06/17

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[10] Yeomans L (2007), "Ergonomic investigation of the risk factors for musculoskeletal disorders associated with the use of pneumatic road breakers", HSL Report NV/07/06

[11] Laboratoire National D'Essais (July 1995), "Measurement of emitted noise in the environment by concrete breakers and picks", Study realised for Commission for European Communities (DGXI); Contract reference B4-3040 (92) 16 HM Eng 009289; LNE reference C.503.W14

[12] Noise Emission in the Environment for use Outdoors (Amendment) Regulations 2005, Statutory Instrument No. 352

[13] The Noise Emission in the Environment by Equipment for Use Outdoors Directive 2000/14/EC. A Guide for Manufacturers to the Evaluation of Uncertainties. First Edition. July 2000

8 APPENDICES

APPENDIX A: Equipment details

Equipment	Serial number
B&K Pulse 3032A 6/1 – Ch input/output module	2325758
DELL Latitude laptop (Pulse 2001)	99123
B&K 4226 multifunction acoustic calibrator	1531353
B&K 2260 Investigator	2305154
B&K 4189 microphone	2294166
B&K 4231 acoustic calibrator	2309005
Position 2	
B&K 4134 microphone	1625411
B&K 2169 preamplifier	608001
B&K 2804 power supply	684342
Position 4	
B&K 4134 microphone	1625402
B&K 2169 preamplifier	418630
B&K 2804 power supply	761775
Position 6	
B&K 4134 microphone	929525
B&K 2169 preamplifier	608004
B&K 2804 power supply	761755
Position 8	
B&K 4134 microphone	982377
B&K 2169 preamplifier	0990257
B&K 2804 power supply	684344
Position 10	
B&K 4133 microphone	519727
B&K 2169 preamplifier	0990252
B&K 2804 power supply	761775
Position 12	
B&K 4133 microphone	771138
B&K 2169 preamplifier	761505
B&K 2804 power supply	684344
Dodecahedron loudspeaker Type 223 Model 010	11360
CEL-213 random noise generator	0170714

APPENDIX B: Individual noise data obtained during simulated real tests

Figures B1 and B2 show the sound power levels obtained for individual operators using each of the breakers during simulated real tests. These levels are compared against the declared and HSL measured noise emission values.

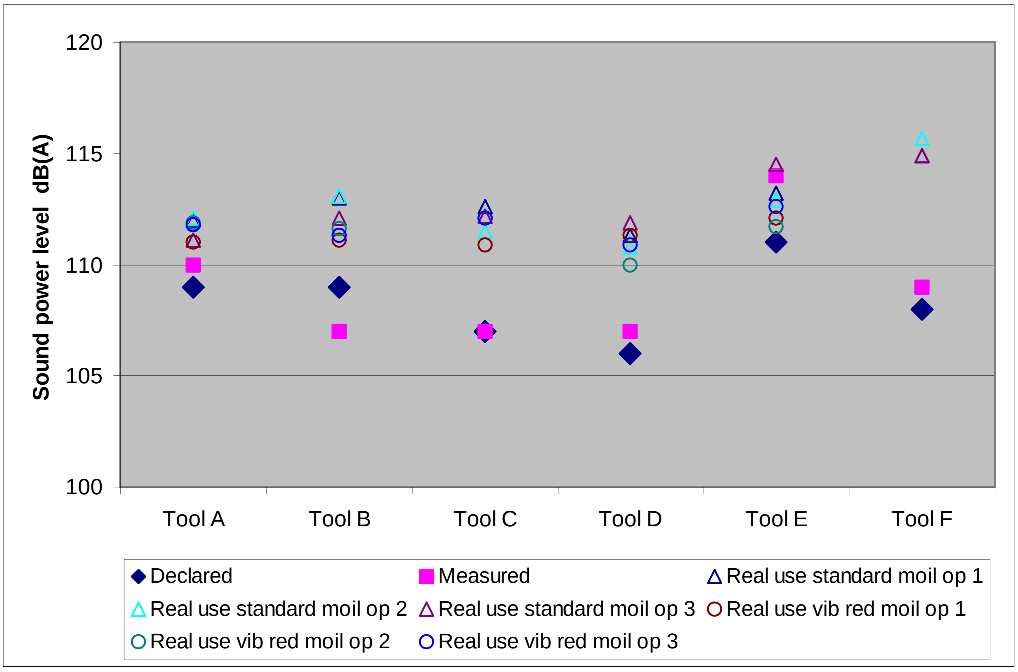

Figure B1: Standard emission data and real use sound power levels (concrete)

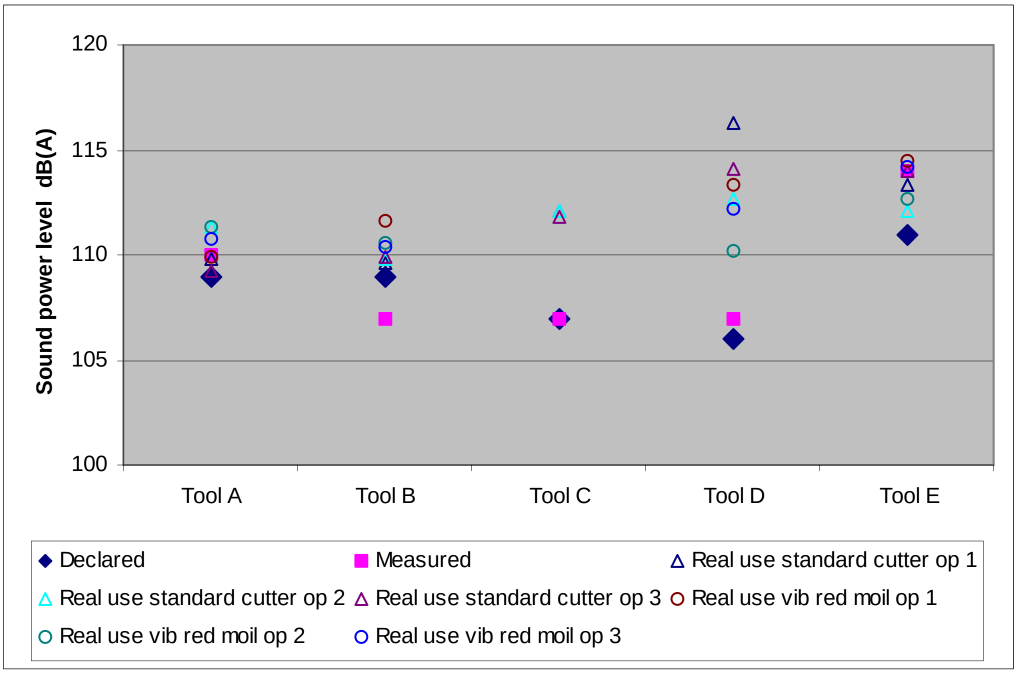

Figure B2: Standard emission data and real use sound power levels (tarmac)

Figures B3 and B4 show the sound pressure levels obtained for individual operators using each of the breakers during simulated real tests. These levels are compared against the declared and HSL measured noise emission values.

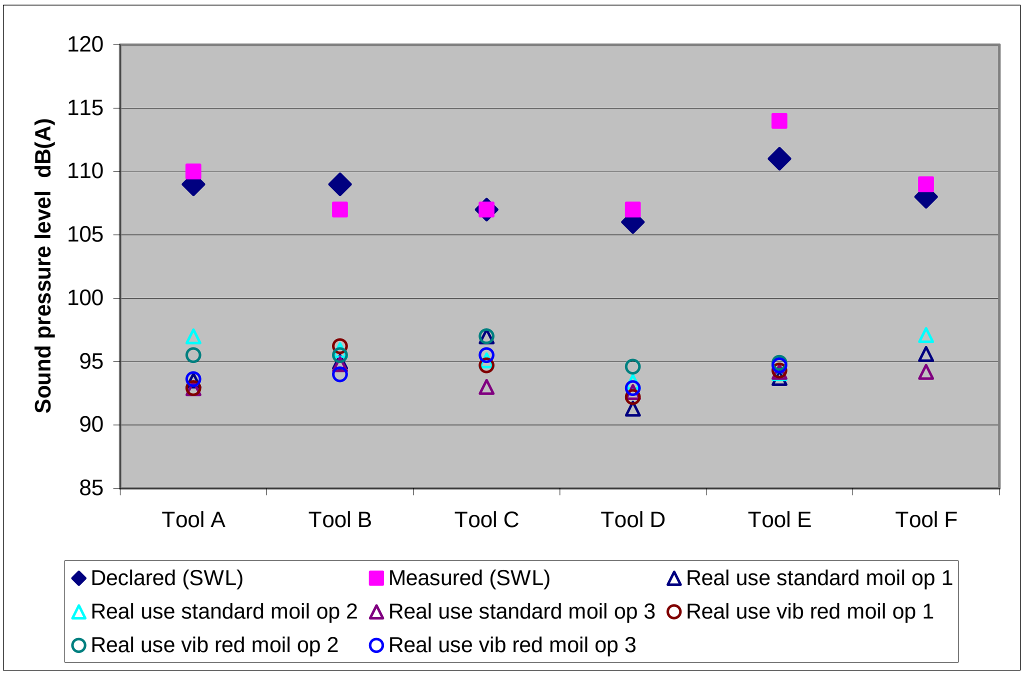

Figure B3: Standard emission data and real use sound pressure levels (concrete)

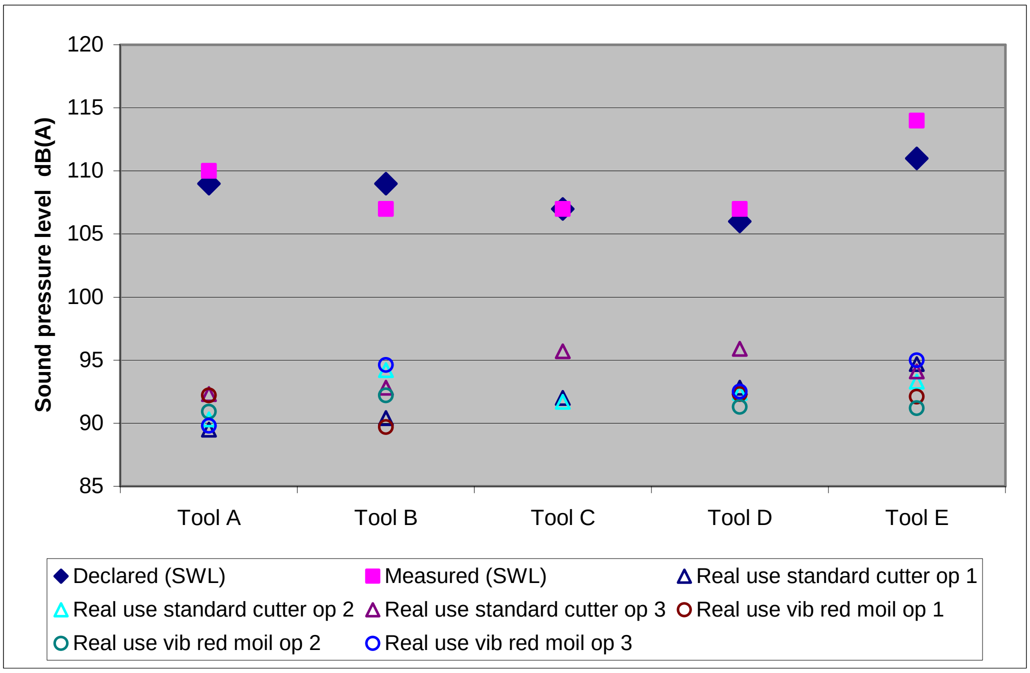

Figure B4: Standard emission data and real use sound pressure levels (tarmac)

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HSE

Health and Safety Executive

Noise emission data for hand-held concrete breakers

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.

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