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Correlation of noise emission of sanders and polishers with in use noise levels

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EXECUTIVE SUMMARY

Objectives

The Control of Noise at Work Regulations 2005, which came into force in April 2006 implementing the EU Physical Agents (Noise) Directive (2003/10/EC), state that employers may use manufacturers' tool data to assess the risk to their employees from exposure to noise.

Until now, HSE has not investigated the use of manufacturers' noise data for these purposes, nor the correlation between the same family of tools e.g. sanders – electric & pneumatic

The objectives of this project were to:
- Measure the noise emission of the tools supplied by the manufacturers and compare to the manufacturers' declared emission, if stated
- Determine whether tools with a declared noise emission have been tested in accordance with the most appropriate test code
- Compare the noise emission of the electric tools when tested according to the pneumatic standard (a fundamental difference in the test codes being that the pneumatic tools are tested under load with an operator whereas the electric tools are free running)
- Comment on the noise test codes for the family of tool under test e.g. should tools be tested with all accessories attached
- Investigate the link between the manufacturers' declared emission and the workstation emission

Main Findings

Airborne noise emission data, required by the Supply of Machinery (Safety) Regulations 1992 (SM(S)R) as amended, varied greatly between manufacturers and between different tools supplied by the same manufacturer. While the regulations and related transposed standards for the family of tools under consideration are clear about declaration requirements, the method of declaration and the quality of data supplied is not always consistent or transparent, making it difficult to compare machines.

Where the manufacturer had stated the test code used, this was also used for the laboratory measurement. In the case of the electrically powered tools supplied, this meant using the partially superseded EN 50144 series of standards. In the case of the pneumatic tools, historical development of the standard from the (CAGI-)PNEUROP trade association publication to the present BS EN ISO 15744 international standard led to a lack of clarity regarding inclusion or otherwise of an uncertainty value associated with the declared emission.

Where declared sound pressure level (L_{pA}) emission information was available, there was some correlation between manufacturers' declared emissions and the results from laboratory measurement – emission data for 5 out of 13 tools were verified. Where declared sound power level (L_{WA}) information was available, an additional sixth tool was also verified. This anomaly arose due to the differences in calculation of L_{WA} for electric and pneumatic tools that require the shape of the measurement surface to be taken into account. Although identical microphone locations are used, a 2dB(A) difference in sound power level can be attributed to the calculation of L_{WA} alone and has nothing to do with the actual noise emission from the tool.

At the time of writing, the EN 50144 safety standard series had been partially superseded by the EN 60745:2003 safety standard series (which mirrors the noise test code in ISO 15744), with a

2006 revision also due. It should be noted that comparison of L_{WA} emission values obtained from EN 50144 and ISO 15774 cannot be drawn on a like-for-like basis due to the 2dB(A) difference obtained through calculation. L_{pA} values are unaffected.

A fundamental difference in the testing of pneumatic and electric powered tools is that the electric tool tests are free running whereas the pneumatic tool tests are under load and require an operator, a defined work piece and work pattern; pneumatic polishers are an exception as they are tested free running. Testing the electric tools to the pneumatic standard, i.e. under load and with an operator, revealed an overall decrease in noise emission from the tool. This is not reflective of the noise emission in the workplace. If the declared emissions for electric tools are to be used in risk assessment then the free running test is more appropriate. The loaded test for pneumatic tools is also appropriate.

Standard tests have the potential to put tools in correct order of relative risk. This enables purchasers and users of machinery to identify low noise designs and make informed choices regarding the safety of a potential purchase from a broad range of tools. In practice, standard test results are only acceptable for relative risk if there is consistency in how the emission data are declared. The standard test results are not acceptable for identifying absolute risk.

Comparison of real use (field) measurement data with the manufacturers' declared workstation emission (where available) revealed differences in L_{pA} values ranging from -0.6 to 23.7 dB(A). This indicates that use of the declared L_{pA} emission values in exposure assessment is likely to underestimate the real use workstation emission level. Real use emission was on average 8.7 ± 6.3 dB(A) higher than the declared emission.

Recommendations

- Alert tool manufacturers to their duties under SM(S)R with regards to provision of airborne noise emission data

- Advise standards bodies and tool manufacturers that reproducibility of declared emissions is not sufficiently high

- Alert end-users of tools that the declared noise emissions may not sufficiently reflect the risk to the worker

- Recommend measurement location at the operator's ear as a priority. SM(S)R require that if the L_{pA} at the operator's ear is greater than 70dB(A) a statement is made to that effect; if the level is greater than 85dB(A) then declare the L_{WA} of the tool.

1 INTRODUCTION

1.1 DECLARATION OF NOISE EMISSION

The Supply of Machinery (Safety) Regulations 1992 as amended [3] place 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 verification of a low noise tool design. Additionally, purchasers and users of machinery are able to make informed choices regarding the safety of a potential purchase.

Standards have been developed in support of the 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 generated in real use, allow tools of the same type to be compared, and identify low-noise tools, highlighting therefore successful low-noise designs. However in practice it can be difficult to design a standard test that is both based on a realistic operation and which gives repeatable results. It is common therefore for standard tests to be based on artificial operations. However in these situations, 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 noise emission standards.

1.2 OUTLINE OF WORK

The aims of the work reported here were to:

- Measure the noise emission of the tools supplied by the manufacturers and compare to the manufacturers' declared emission, if stated
- Determine whether tools with a declared noise emission have been tested in accordance with the most appropriate test code
- Compare the noise emission of the electric tools when tested according to the pneumatic standard (a fundamental difference in the test codes being that the pneumatic tools are tested under load with an operator whereas the electric tools are free running)
- Comment on the noise test codes for the family of tool under test e.g. should tools be tested with all accessories attached
- Investigate the link between the manufacturers' declared emission and the workstation emission

This project was carried out in conjunction with HSL project JR45.085, an investigation into the correlation between vibration emission and vibration during real use on sanders and polishers as reported in NV/06/18 [17].

1.3 TERMINOLOGY FOR EMISSION DATA

The noise emission data declared by the manufacturer and supplied with the sander or polisher (where available) is referred to as the "declared emission".

The noise emission measured by HSL in accordance with the requirements of the relevant standard is referred to as the "measured emission".

2 TOOLS TESTED

Thirteen new tools were obtained for testing. Details of the tools are given in Table 1.

Table 1. Tool details

Tool	Tool type	Motor	Speed (rpm)	Action
A	Sander	Pneumatic	9500	random orbital
B	Sander	Pneumatic	12000	random orbital
C	Sander	Pneumatic	12000	random orbital
D	Sander	Pneumatic	10000	orbital
E	Sander	Pneumatic	12000	random orbital
F	Sander	Pneumatic	10000	orbital
G	Sander	Electric 240V	4000 – 11000	random orbital
H	Sander	Electric 240V	11000	orbital
I	Sander	Pneumatic	10000	random orbital
J	Polisher	Pneumatic	10000	random orbital
K	Polisher	Electric 110V	2000	angle
L	Polisher	Pneumatic	2100	angle
M	Sander	Electric 110V	10000	orbital

All tools except Tools I and K were loaned by tool manufacturers and supplied with varying degrees of declared emission information. Tools I and K were bought for the purposes of the project. Table 2 shows the declared noise emission information available with the tools. The information supplied with Tools I and K was not sufficiently clear to allow inclusion of the values in any subsequent analysis.

Table 2. Tool declared emission data

Tool	Test method quoted	Declared emission (dB)			
		L_{pA}	K_{pA}	L_{WA}	K_{WA}
A	dB(A) SPL @ 1m PN8NTC1.2	79	3*	-	-
B	dB(A) SPL/SWL @ 1m	78	3*	91	3*
C	dB(A)SPL/SWL @ 1m	78	3*	91	3*
D	dB(A) SPL/SWL @ 1m	80	3*	93	3*
E	dB(A) CAGI-PNEUROP ISO 3744	72^{+}	2*	85	± 2
F	dB(A)EN ISO 15744	82	3*	-	-
G	BS EN 50144-2-4:1999	84.6	2*	97.5	2*
H	No data available	-	-	-	-
I	80dB(A) – numeric value is unqualified	-	-	-	-
J	dB(A) SPL/SWL @ 1m	79	3*	92	3*
K	88.7dB EN 50144 – numeric value is unqualified	-	-	-	-
L	dB(A) PN8NTC1.2	71	± 3	-	-
M	dB(A) EN 50144	73.4	2*	-	-

*These values have been estimated in accordance with the relevant method quoted and assume a *K* value has not already been included in the declared emission.

$^{+}$This value has been estimated based on the declared L_{WA}-13dB. It assumes a measurement surface area of 20m^2.

3 LABORATORY MEASUREMENTS

3.1 LABORATORY TEST CODES

The measurement of the noise emission from sanders and polishers has as its basic measurement standard BS EN ISO 3744:1995 “Acoustics, Determination of sound power levels of noise sources using sound pressure – Engineering method in an essentially free field over a reflecting plane” [4]. The choice of test code is, however, dependent on the tool type and how it is powered. Of the 13 tools tested these can be split into four groups:

1. Pneumatic sanders (7 tools)
2. Pneumatic polishers (2 tools)
3. Electric sanders (3 tools)
4. Electric polishers (1 tool)

For all four groups sound pressure level measurements are required at five defined microphone positions. These values are then used to calculate the sound power level of the tool. The tests for pneumatic sanders are under load, require an operator, a defined work piece and a defined work pattern, using a test methodology very similar to that used for vibration emission testing of the pneumatic tools. Electric tools and pneumatic polishers are tested free running, without an operator.

3.1.1 Pneumatic tools test codes

3.1.1.1 Noise emitted from the tool over a defined measurement surface

The specific test code for pneumatic tools, as referred to in the safety standard BS EN 792-8:2001 [15], is:

BS EN ISO 15744:2002
Hand-held non-electric power tools. Noise measurement code. Engineering method (grade 2) [5]

This standard requires the A-weighted sound pressure levels to be measured directly at five defined microphone positions on a measurement surface of a hemisphere standing on a cylindrical pedestal enveloping the tool (see Figure 1.). The five microphone positions are located 1m from the geometric centre of the tool. Four of the positions are spaced at regular intervals on a plane defined as passing through the geometric centre of the tool and parallel to the reflecting plane. The fifth position is located at a distance of 1m above the geometric centre of the tool. The A-weighted sound power level, L_{WA}, is calculated from the following:

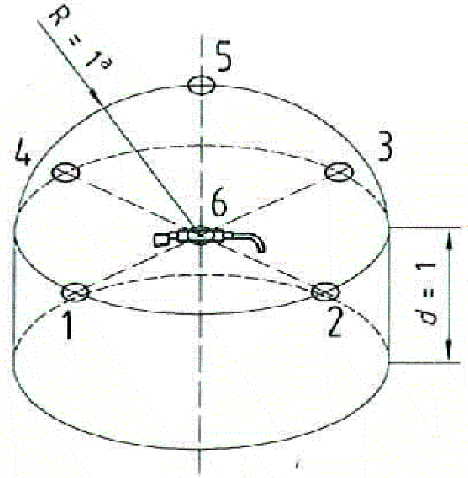
$$L_{WA} = \overline{L_{pfA}} + 10\log\left(\frac{S}{S_0}\right)\text{dB}$$

with $\overline{L_{pfA}}$ determined from:

$$\overline{L_{pfA}} = 10\log\left(\frac{1}{5}\sum_{i=1}^{5}10^{0.1L'_{pAi}}\right) - K_{1A} - K_{2A}$$

where:

$\overline{L_{pfA}}$	is the A-weighted surface sound pressure level, dB
L'_{pAi}	is the A-weighted sound pressure level at the *i*-th microphone position, dB
K_{1A}	is the A-weighted background noise correction
K_{2A}	is the A-weighted environmental correction
S	is the measurement surface area, 4π m^2
S_0	1 m^2



Key
1 to 5 Microphone position
6 Geometric centre of power tool
a Radius of hemisphere

Figure 1. Measurement surface for BS EN ISO 15744

For all the pneumatic tools tested at HSL no environmental correction was required as the measurements were made in a semi-anechoic chamber (see Figure 2.). Background noise corrections were also not necessary because the difference between the surface sound pressure level with and without the tools in operation was greater than 15 dB; it was typically greater than 40 dB.

Clause 9 of the standard requires the measurements to be made three times and the average value to be retained as the measured emission
i.e. L_{WA} of tool = (L_{WA} 1st measurement + L_{WA} 2nd measurement + L_{WA} 3rd measurement)/3

For pneumatic orbital and random orbital sanders, the measurements are carried out during a sanding operation performed by a trained operator. The sander, equipped with sanding paper of grade 180 grit and operated on a horizontal rigid steel plate, has a 30 N ± 5 N feed force applied vertically downwards whilst the trained operator moves the sander over the surface of the steel plate in a figure-of-eight pattern, according to ISO 8662-8, each figure-of-eight pattern taking approximately 4 s to complete.

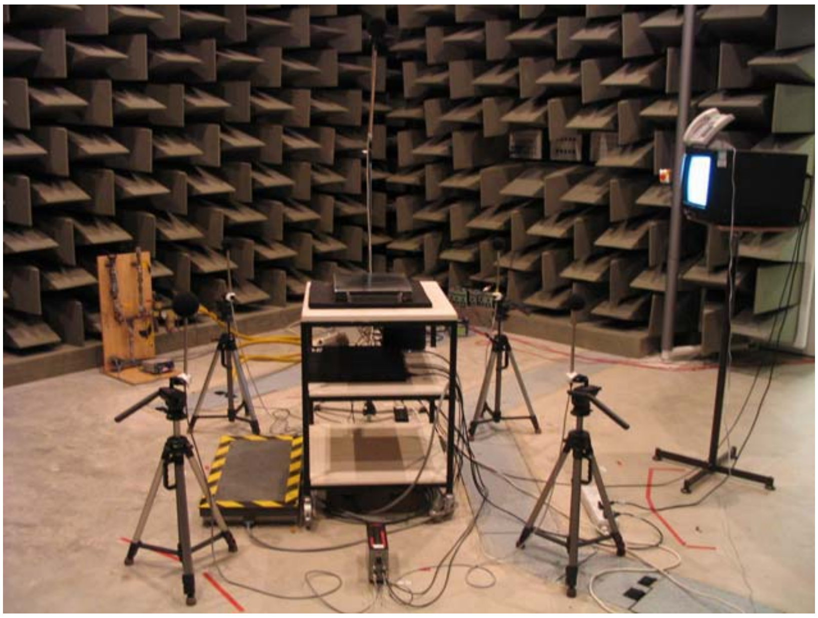


Figure 2. Test rig for pneumatic sanders

For pneumatic polishers, measurements were carried out under no-load conditions. This was achieved by suspending the tools from a frame fixed to loading bolts contained in the roof of the semi-anechoic chamber (see Figure 4).

3.1.1.2 Emission sound pressure level at the workstation

The L_{WA} value may also be used to calculate the A-weighted emission sound pressure level at the workstation, L_{pA}. This is done according to ISO 11203 [6] using the following equation:

$$L_{pA} = L_{WA} - Q$$

where Q = 11 dB. The evaluation for this is given in BS EN ISO 15744. It should be noted that because no background or environmental corrections were applied in the calculation of the L_{WA}, the L_{pA} equals the $\overline{L_{pfA}}$.

3.1.1.3 C-weighted peak emission sound pressure level at the workstation

The C-weighted peak emission sound pressure level, $L_{pC,peak}$, at the workstation is the highest C-weighted peak sound pressure level measured at any of the five microphone positions at any point during a measurement series on a tool with no corrections applied.

3.1.1.4 Declarations

Each tool should have a declared noise emission value. The declaration of the noise emission values are made as a dual number noise emission declaration in accordance with ISO 4871:1996 [16]. The L_{pA}, $L_{pC,peak}$ and L_{WA} are declared with their respective uncertainties K_{pA}, $K_{pC,peak}$ and K_{WA}. The likely uncertainty value is 3 dB.

3.1.2 Electric tools test codes

At the time of writing, the standard series for the safety of hand-held electric power tools was undergoing revision from the EN 50144 series [7] [8] [9] to the EN 60745 series [10] [11]. As may be seen from Table 2 the electrically powered tools have been declared according to the EN 50144 series. Whilst there is no fundamental change in how noise measurements are made under laboratory conditions there is a difference in how the declared sound power level is calculated. In EN 50144, the measurement surface is shown to be a cube with five discrete microphone locations. This gives a measurement surface area of 20 m^2. In EN 60745 the same five microphone locations are retained but the measurement surface is defined as a hemisphere standing on a cylindrical pedestal. This gives a measurement surface of 4π m^2 (12.56 m^2). In both cases the sound power level of the tool is calculated using the following equation:

$$L_{WA} = \overline{L_{pfA}} + 10\log\left(\frac{S}{S_0}\right)\text{dB}$$

where:

$\overline{L_{pfA}}$	is the surface sound pressure level
S	is the measurement surface area
S_0	1 m^2

For EN 50144, with S = 20 m^2, this equates to $L_{WA} = \overline{L_{pfA}} + 13$

For EN 60745, with S = 12.56 m^2, this equates to $L_{WA} = \overline{L_{pfA}} + 11$

This means a difference of 2 dB(A) in declared sound power emissions through calculation alone. Whilst this difference in standards will not affect the findings of this report, it should be noted that declared sound power emission values from the two different standards must not be compared on a like-for-like basis.

3.1.2.1 Noise emitted from the tool over a defined measurement surface

For the purposes of this report, the specific test codes (and their EN status) employed for electric hand-held tools are:

BS EN 50144-1:1996
Safety of hand-held electric motor operated tools. Part 1: General requirements
(current, revised, work in hand)

BS EN 50144-2-3:2002
Safety of hand-held electric motor operated tools. Part 2-3: Particular requirements for grinders, disk type sanders and polishers
(current)

BS EN 50144-2-4:2000
Safety of hand-held electric motor operated tools. Part 2-4: Particular requirements for sanders
(superseded, withdrawn)

For clarity, the following standards are those current at time of writing:

BS EN 60745-1:2003
Hand-held motor-operated electric tools. Safety. Part 1: General requirements
(current, work in hand)

BS EN 60745-2-4:2003
Hand-held motor-operated electric tools. Safety. Part 2-4: Particular requirements for sanders and polishers other than disk type
(current, work in hand)

EN 50144-1 requires the A-weighted sound pressure levels to be measured directly at five defined microphone positions on a cube shaped measurement surface (see Figure 3.). The five microphone positions are located 1 m from the geometric centre of the tool. Four of the positions are spaced at regular intervals on a plane defined as passing through the geometric centre of the tool and parallel to the reflecting plane. The fifth position is located at a distance of 1 m above the geometric centre of the tool. The A-weighted sound power level, L_{WA}, is calculated from the following:

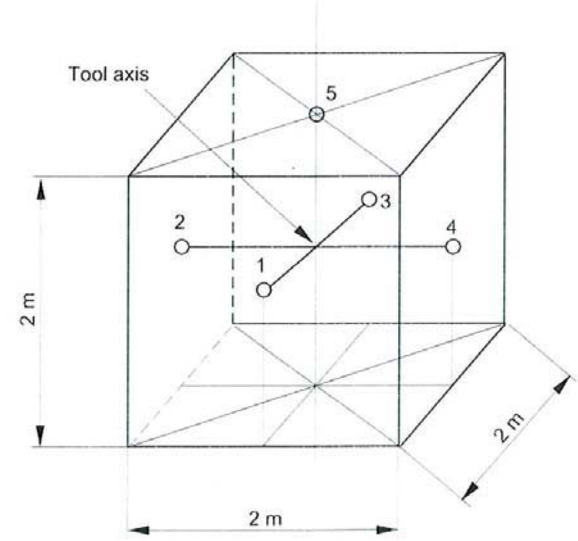
$$L_{WA} = \overline{L_{pA}} + 10\log\left(\frac{S}{S_0}\right)\text{dB}$$

with $\overline{L_{pA}}$ determined from:

$$\overline{L_{pA}} = 10\log\left(\frac{1}{5}\sum_{i=1}^{5}10^{0.1L_{pAi}}\right)$$

where:

$\overline{L_{pA}}$	is the A-weighted surface sound pressure level, in dB re 20µPa
L_{pAi}	is the A-weighted sound pressure level at the *i*-th microphone position, in dB re 20µPa
S	is the measurement surface area, 20 m^2
S_0	1 m^2



Key
1 to 5 Microphone position

Figure 3. Measurement surface for BS EN 50144

The tool was positioned such that its main axis was at 45° between the microphone positions 1-4 and 2-3. Measurements were considered valid if the difference between the background noise and the tool under test was at least 10 dB. The difference was typically greater than 40 dB.

Clause 13.2.4 of EN 50144-1 requires three consecutive tests to be carried out and the arithmetic mean of the three, rounded to the nearest decibel, to be retained as the measured emission, i.e.:

L_{WA} of tool = (L_{WA} 1st measurement + L_{WA} 2nd measurement + L_{WA} 3rd measurement)/3

Figure 4. Test rig for electric sanders & polishers (and pneumatic polishers)

3.1.2.2 Emission sound pressure level at the workstation

EN 50144 does not give any guidance regarding the measurement of the noise level at the operator’s ear save for one note at the end of Clause 13.2.6 that reads:

“NOTE. The emission sound pressure level related to the workplace is assumed to be the surface sound pressure level.”

Clause 7.13.1 requires that the:

“…continuous A-weighted equivalent sound pressure level at the operator’s ear” be included in the instruction sheet for the tool “if over 70 dB(A) or a statement to the effect if it does not exceed 70 dB(A)”.

Despite notes in standards not being normative, the inference is that the surface sound pressure level should be taken as the emission sound pressure level related to the workplace. This has been addressed to some degree in EN 60745 with the inclusion in Clause 6.1 of a definitive calculation, identical to that of EN 15744. In both cases, the noise at the operator’s ear declaration value is still equivalent to the surface sound pressure level at 1 m but with the option in a further note to correct for a distance of less than or greater than 1 m.

A workstation location was defined by HSL as being at 0.65 m above the geometric centre of the tool, i.e. 1.65 m above the ground at a position representative of the worker’s ear. Measurements were taken at this location for the four electric tools provided. Three consecutive measurements were made and the arithmetic average of the three retained as the measured emission sound pressure level.

3.1.2.3 C-weighted peak emission sound pressure level at the workstation

Clause 7.13.1 of EN 50144 requires the "C-weighted instantaneous sound pressure level if over 63 Pa (130 dB in relation to 20 µPa)" to be included in the instruction manual for the tool. As with the emission sound pressure level at the workstation the standard gives no guidance as to how this value should be obtained. Guidance has therefore been taken from the pneumatic test code. The highest C-weighted peak sound pressure level measured at any of the five microphone positions at any point during a measurement series on a tool with no corrections applied was taken as the C-weighted peak emission sound pressure level.

3.1.2.4 Declarations

In terms of noise information, Clause 7.13.1 of EN 50144 clearly states that the instruction sheet for the tool shall include at least:

a) The continuous A-weighted equivalent sound pressure level at the operator's ear if over 70 dB(A), or a statement to the effect if it does not exceed 70 dB(A)

b) The peak C-weighted instantaneous sound pressure level if over 63 Pa (130 dB in relation to 20 µPa)

c) The sound power level emitted by the tool where the equivalent continuous sound pressure level exceeds 85 dB(A)

d) When necessary, instructions concerning the use of ear protection.

3.1.2.5 EN 60745 requirements

The requirements of EN 60745, the successor of EN 50144, are identical to those of the pneumatic test code, EN 15744.

3.2 MEASURED EMISSION RESULTS

A combination of measurement methods were used to obtain the sound pressure level readings at the specified microphone positions. For Tools G, H, K and M (electric) a Brüel & Kjær type 2260 sound level meter was used. A 30 s L_{eq} measurement was made sequentially at each of the five microphone locations and then at the defined operator ear location of 0.65 m above the geometric centre of the tool. For the remaining tools (pneumatic), microphones on tripods were located at each of the measurement positions. These were connected to microphone power supplies and the output routed to a Brüel & Kjær PULSE analysis system for real time analysis. Simultaneous noise measurements were made at the five microphone positions during testing, again using a 30 s linear averaging time.

For all tools, the sound pressure level values obtained at the microphone positions were used to calculate the surface sound pressure level, the sound power level and where applicable the noise level at the workstation. Table 3 shows the noise emission values from the tests carried out by HSL against those values declared by the manufacturers of the tools. It may be seen that Tools E, F and L have two measured emission values. This is because the tools were supplied with different exhaust options or attachments. E.1 and F.1 refer to the attachment of a hose and dust bag; E.2 and F.2 refer to the use of a silenced exhaust; L.1 is the use of the tool without the hose sleeve over the airline and L.2 is with the hose sleeve over the airline. It was considered appropriate to test the tools with all available options. A full summary of the emission test results may be found in Appendix A whilst full result details may be found in Appendix B.

Figure 5 shows the declared sound pressure level against the measured surface sound pressure level. Figure 6 shows the declared sound power level against the measured sound power level. The result for Tool K is for the tool without its polishing pad and side handle.

Table 3. Declared emission vs measured emission & verification

Tool	**Declared emission (dB)**		**Measured emission (dB)**		**Verified**	**Declared emission (dB)**		**Measured emission (dB)**		**Verified**
	L_{pA}	K_{pA}	L_{pA}	K_{pA}		L_{WA}	K_{WA}	L_{WA}	K_{WA}	
A	79	3*	81.7	3.0	Yes	-	-	92.7	3.0	-
B	78	3*	83.6	3.0	No	91	3*	94.5	3.0	No
C	78	3*	82.9	3.0	No	91	3*	93.8	3.0	Yes
D	80	3*	74.1	3.0	Yes	93	3*	85.0	3.0	Yes
E.1	72+	2*	88.9	3.0	No	85	± 2	99.9	3.0	No
E.2			77.7	3.0	No			88.7	3.0	No
F.1	82	3*	81.1	3.0	Yes	-	-	92.0	3.0	-
F.2			77.0	3.0	Yes			87.9	3.0	-
G	84.6	2*	87.4	2.0	No	97.5	2*	100.4	2.0	No
H	-	-	80.6	2.0	-	-	-	93.5	2.0	-
I	-	-	79.6	3.0	-	-	-	90.6	3.0	-
J	79	3*	79.3	3.0	Yes	92	3*	90.3	3.0	Yes
K	-	-	81.8	2.0	-	-	-	94.8	2.0	
L.1	71	± 3	74.7	3.0	No	-	-	85.7	3.0	
L.2			68.4	3.0	Yes			79.4	3.0	
M	73.4	2*	76.8	2.0	No	-	-	89.8	2.0	

*These values have been estimated in accordance with the relevant method quoted and assume a *K* value has not already been included in the declared emission.
+This value has been estimated based on the declared L_{WA}-13dB. It assumes a measurement surface area of 20m^2.

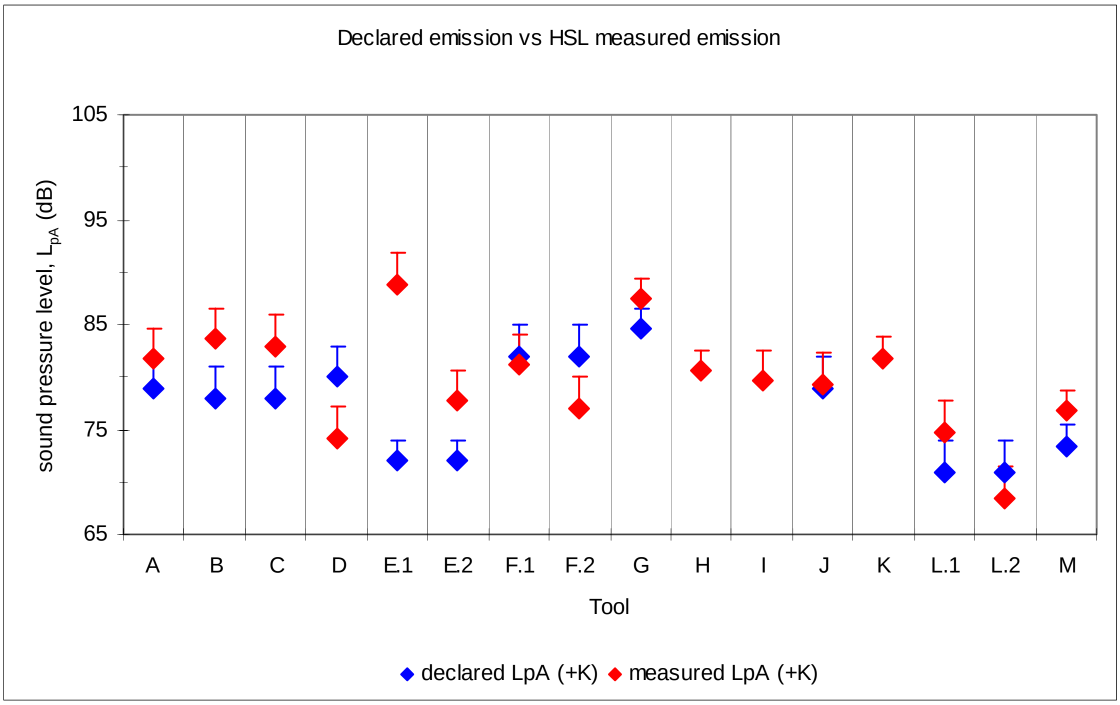


Figure 5. Declared sound pressure level vs measured surface sound pressure level

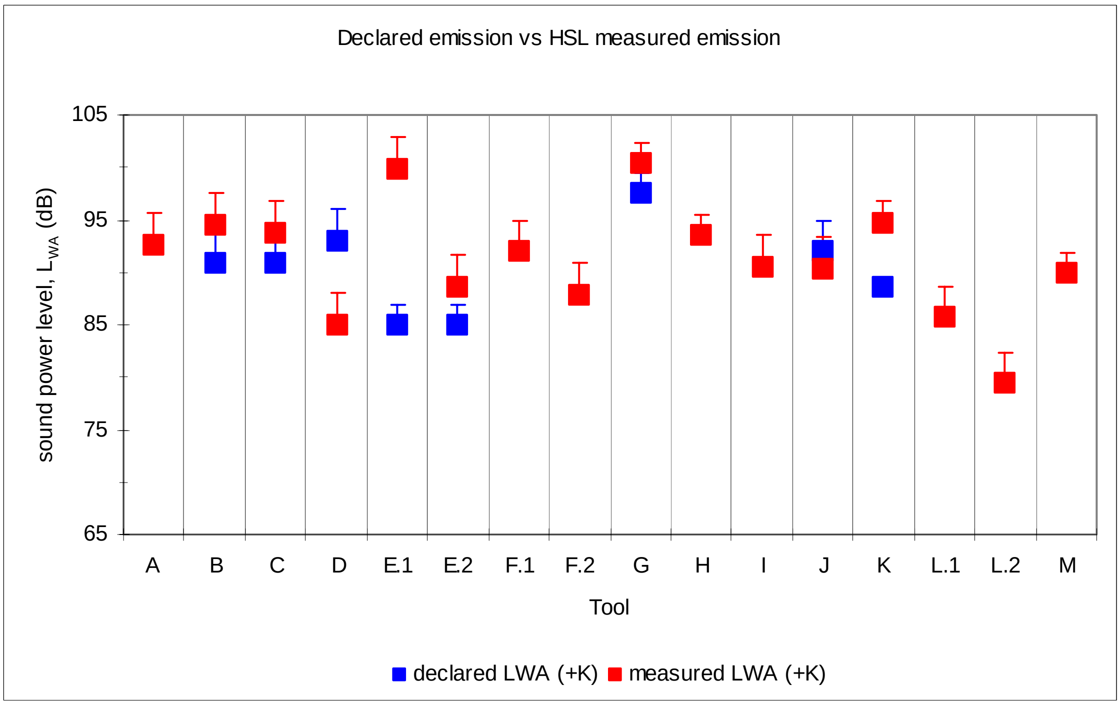


Figure 6. Declared sound power level vs measured sound power level

Table 3 also shows whether the manufacturer's declared emissions have been verified. Verification has been carried out in accordance with BS EN ISO 4871:1997 [16] wherein it is stated that (laboratory) measured emission must be less than or equal to the declared emission plus the uncertainty value i.e. $L_{measured} \leq L_{declared} + K_{declared}$.

Considering only the L_{pA}, tools A, D, F, J and L.2 have been verified. If L_{WA} is considered, then tool C is also verified. This anomaly arises due to the differences in calculation for L_{WA} as highlighted in Section 3.1.2. The L_{WA} calculation is based on the L_{pA} and a defined surface area. Tools A, C, D, F, J and L are all pneumatic but as Table 2 shows they are not all declared to the same standard. Tool F is the only one declared to the current BS EN ISO 15744:2002. This uses the hemisphere on a cylindrical pedestal measurement surface (Figure 1). In calculation terms, $L_{WA} = L_{pA}$ +11dB. The remainder of this group either uses a selection of historic pneumatic tools test codes or the test code is not referenced. From the declared values in Table 2, for tools C, D and J, it can be seen that $L_{WA} - L_{pA}$ = 13dB. This would indicate that a cube shaped measurement surface has been used to calculate L_{WA} (Figure 3). For tool C, this difference in calculation is the difference between a verified and non-verified tool. Due to the ambiguous nature of the L_{WA} declarations, these will not be used in further analysis; only the L_{pA} values will be considered. This is consistent with the current Machinery Safety Regulations [3], which place emphasis on knowing the level at the operator's ear. For all tools, the L_{pA}, declared or measured, is taken as the level at the operator's ear.

Figure 7 shows the measured L_{pA} emission results against the standard deviation of the measurement. Displaying the data in this way highlights the grouping of the tools.

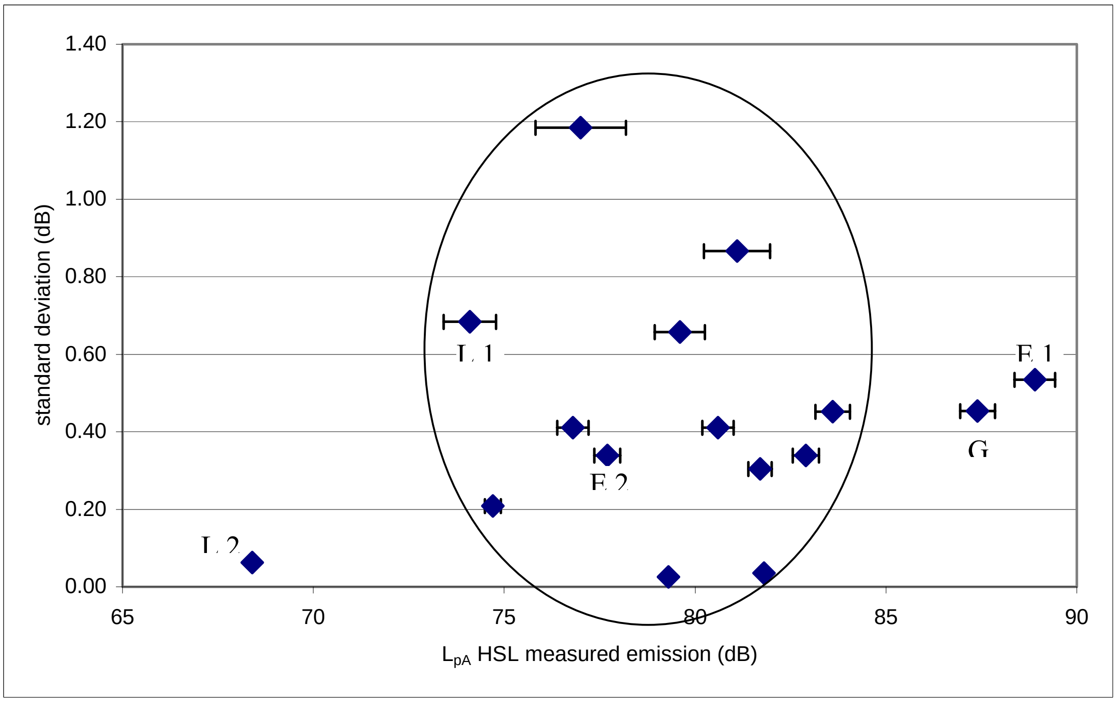


Figure 7. L_{pA} HSL measured emission vs standard deviation

As Figure 7 shows, the majority of the tools lie between approximately 75dB and 85dB L_{pA}. Tool L.2 is identified as low noise while tools G and E.2 are identified as having higher measured emission values. Tools E.2 and L.1 are identified for completeness.

4 ADDITIONAL LABORATORY MEASUREMENTS

4.1 TESTING ELECTRIC TOOLS TO THE PNEUMATIC TEST CODE

Section 3.1 discussed the differences in test codes for electric and pneumatic tools. Further to this discussion, the electric Tools G, H, K and M were tested according to the criteria laid out in the pneumatic test code, EN 15744. Table 4 and Figure 8 show the results obtained.

Table 4. Electric tool noise emissions when tested according to the pneumatic tools test code

Tool	Type	EN 50144 (free running)		EN ISO 15744 (loaded)		
		Measured L_{pA} (dB)	Measured L_{WA} (dB)	Measured L_{pA} (dB)	Measured L_{WA} (dB)	Feed force N
G	Sander	87.4	100.4	81.8	92.8	50 ± 5
H	Sander	80.6	93.5	76.7	87.7	50 ± 5
K	Polisher	81.8	94.8	82.6	93.6	30 ± 5
M	Sander	76.8	89.9	72.9	83.9	50 ± 5

Note: For EN 50144, $L_{WA} - L_{pA}$ = 13dB; this is due to the cube shaped measurement surface used to calculate L_{WA}. For EN ISO 15744, $L_{WA} - L_{pA}$ = 11dB; this is due to the hemisphere on a cylindrical pedestal measurement surface. For this reason, L_{WA} is not plotted in Figure 7.

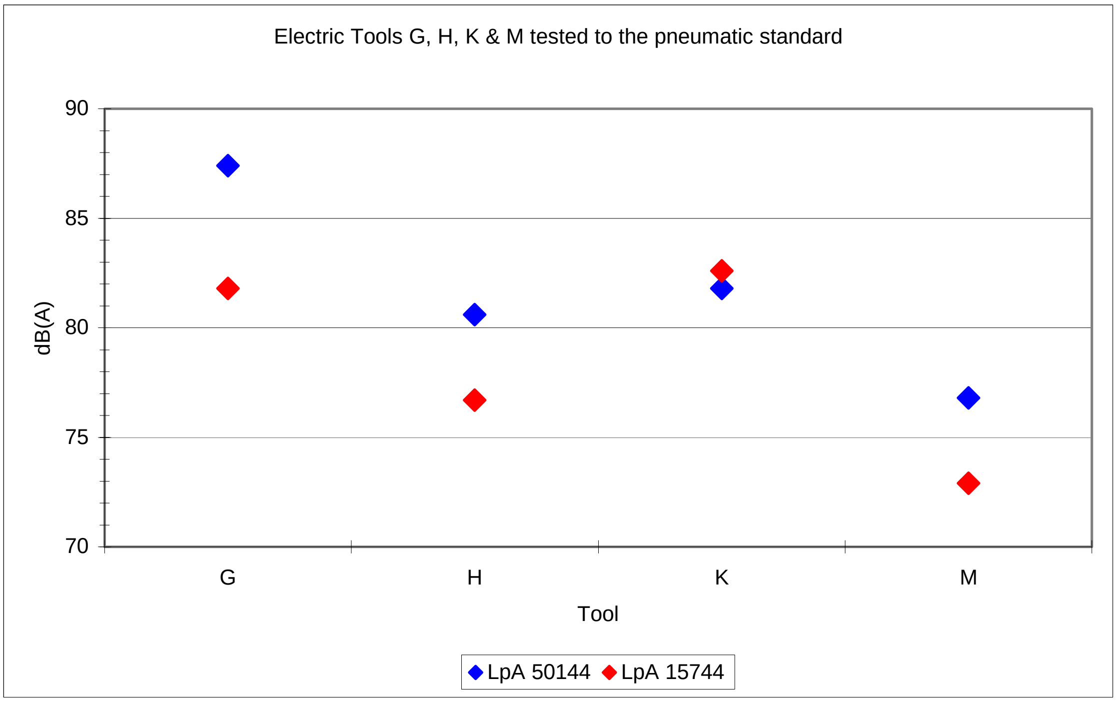


Figure 8. Electric tools tested to pneumatic test standard

In the case of the three sanders, the application of a feed force by an operator using the standard figure-of-eight pattern on a rigid steel plate resulted in a lower value of L_{pA}. For Tool K, the L_{pA} was slightly increased. It was noted during testing that this tool had powerful exhaust ventilation and that due to the nature of the test, one of the exhaust vents pointed directly at one of the microphone locations. This exhaust vent was also a major source of motor noise for the tool.

4.2 PNEUMATIC POLISHERS UNDER LOAD

EN ISO 15744 requires that pneumatic polishers normally be tested free running. The results for these tests are reported in Section 3.2. Additionally, the pneumatic polishers Tools J and L were retested using the same criteria as for pneumatic sanders (a skilled operator, known feed force, figure-of-eight sanding pattern etc). Table 5 and Figure 9 show the results obtained.

Table 5. Results for pneumatic polishers tested under load

Tool	Type	Free running		Loaded		
		Measured L_{pA} (dB)	Measured L_{WA} (dB)	Measured L_{pA} (dB)	Measured L_{WA} (dB)	Feed force N
J	Polisher	79.3	90.3	78.6	89.6	30 ± 5
L	Polisher	68.4	79.4	74.6	85.6	30 ± 5

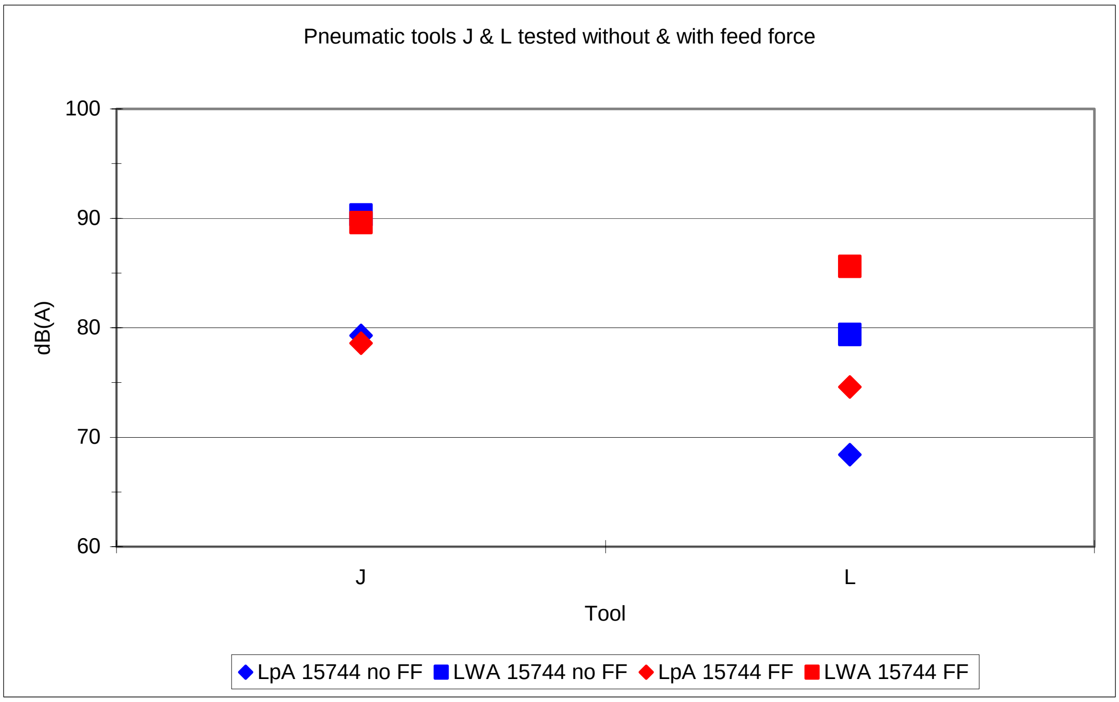


Figure 9. Results for pneumatic polishers tested under load

When tested under load, the results for Tool J remained largely unaffected. Tool L however experienced an increase in both sound pressure and inherently the sound power levels.

4.3 TOOL K WITH AND WITHOUT ALL ACCESSORIES AND ATTACHMENTS

Tool K is a multiple application tool depending on which attachment is used. It has the option of a side handle with guard and a large foam polishing pad. The measured emission as reported in Section 3.2 was the noise emitted from the main body of the tool without the polishing pad and side handle and guard attached. Table 6 shows the results obtained when the tool was tested with its various attachments. It should be noted that the ‘no attachments’ condition was in full conformance with EN 50144. The remaining three conditions had one test run each instead of the standard three. (Note that Tool K is an electric tool and was therefore tested in a free-running no load condition.)

Table 6. Results for Tool K under various conditions

Attachment details	**Measured (lab)**	
	Measured L_{pA} (dB)	**Measured L_{WA} (dB)**
No attachments	81.8	94.8
With polishing pad only	81.9	94.9
With handle & guard on LHS of tool only	82.1	95.1
With handle & guard on RHS of tool only	82.2	95.2

In the case of Tool K the addition of the polishing pad or handle and guard does not significantly affect either the sound pressure or sound power levels. The standard deviation across sound pressure and sound power levels for the four different free running conditions is 0.18dB (one test run). The standard deviation for the no attachments condition (measured emission) is 0.04dB (three test runs).

5 REAL USE MEASUREMENTS

As part of the laboratory based emission tests, the sound pressure level at the operator's ear was either measured or calculated depending on the test code involved. An expansion to the original aims of the project, this section reports the results of those measurements or calculations against actual measurements made at operators' ears during five site visits.

BS EN ISO 11202:1996 "Acoustics. Noise emitted by machinery and equipment. Measurement of emission sound pressure levels at a workstation or other specified positions. Survey method in situ" [12] was used as the test method for carrying out these measurements. The emission sound pressure level, L_{pA}, is given by:

$$L_{pA} = L'_{pA} - K_{1A} - K_{3A} \text{ dB(A)}$$

where:

L'_{pA} is the A-weighted measured sound pressure level at the operator's ear
K_{1A} is the A-weighted correction for background noise
K_{3A} is the A-weighted local environmental correction

K_{1A} is calculated from:

$$K_{1A} = -10\log\left(1 - 10^{-0.1\Delta L}\right) \text{ dB(A)}$$

where:

ΔL is the difference between the sound pressure levels measured, at a specified position, with the tool under test in operation and turned off, respectively
If $\Delta L > 10$ dB, K_{1A} is assumed to equal 0; if $\Delta L < 3$ dB the measurement is invalid; if ΔL is between the two, the correction for background noise is applied.

K_{3A} is calculated from:

$$K_{3A} = 10\log\left(1 + 4\frac{S}{A}\right) \text{dB(A)}$$

where:

S is $2\pi a$ and a is the distance, in metres, from the specified position to the closest major sound source of the tool
A is αS_v; α is the mean acoustic absorption coefficient of the test environment estimated from table A.1 in Annex A of ISO 3746 [13]; S_v is the total area of the test environment (walls, ceiling, floor), m^2

Calculation of K_{3A} has been shown to be less than 0.05 dB(A) for each of the five sites visited and has therefore not been included (measurements on site were taken to one decimal place). K_{1A} has been applied where required according to the criteria given above.

At each site visited, a Brüel & Kjær type 2260 sound level meter was used to record a 30 second linear average at the operator's ear whilst a skilled operator sanded or polished a typical work piece. This was done for all operators for each tool. In some cases only two operators, instead of the preferred three, were available at a site due to restrictions on human resources. Whether two or three operators were used, the logarithmic average of the measurements for each tool was taken and this was retained as the L'_{pA} for that tool at that site.

5.1 MEASUREMENT & RESULTS

Table 7 and Figure 10 show the results from the five site visits. It should be noted that the results for sites 2 and 3 have been combined to make one site as site 2 only had pneumatic capability and site 3 had only electric capability. Full results from the field visit measurements may be found in Appendix C.

Table 7. Sound pressure level at the operator's ear; showing the L'_{pA}, the value of the background noise correction, K_{1A}, the number of measurements made at each site for each tool and the standard deviation across all sites

Tool	L'_{pA}, sound pressure level at the operator's ear (dB)												
	Site #1			Site #2 & #3			Site # 4			Site # 5			Std dev
	L'_{pA}	K_{1A}	No.	L'_{pA}	K_{1A}	No.	L'_{pA}	K_{1A}	No.	L'_{pA}	K_{1A}	No.	
A	85.6	1.2	3	85.7	0.0	3	85.2	0.0	3	94.0	0.0	3	4.27
B	86.2	1.0	3	89.6	0.0	2	89.1	0.0	3	89.1	0.0	3	1.58
C	86.3	1.0	3	89.7	0.0	3	89.0	0.0	3	90.3	0.0	3	1.77
D	80.7	2.9	3	82.7	0.7	3	83.5	0.5	3	83.9	0.0	3	1.43
E.1	-	-	-	-	-	-	-	-	-	95.7	0.0	3	n/a
E.2	84.1	1.6	3	83.8	0.0	3	81.6	0.8	3	-	-	-	1.37
F.1	-	-	-	86.0	0.0	3	-	-	-	86.7	0.0	3	0.52
F.2	n/a	3.9	3	-	-	-	81.4	0.8	3	-	-	-	n/a
G	94.4	0.0	3	98.9	0.0	2	-	-	-	-	-	-	3.18
H	87.1	0.8	3	87.0	0.0	2	-	-	-	-	-	-	0.05
I	85.6	1.2	3	87.3	0.9	3	85.4	0.0	3	87.3	0.0	3	1.04
J	86.2	0.0	2	-	-	-	85.7	0.0	3	82.7	0.5	3	1.87
K	91.8	0.0	2	-	-	-	-	-	-	90.9	0.0	3	0.66
L.1	90.5	0.0	2	-	-	-	81.9	0.7	3	-	-	-	6.12
L.2	-	-	-	-	-	-	-	-	-	74.3	2.9	3	n/a
M	83.5	1.7	3	86.6	0.0	2	-	-	-	-	-	-	2.19

Reminder: E.1 and F.1 refer to the attachment of a hose and dust bag; E.2 and F.2 refer to the use of a silenced exhaust; L.1 is the use of the tool without the hose sleeve over the airline and L.2 is with the hose sleeve over the airline.

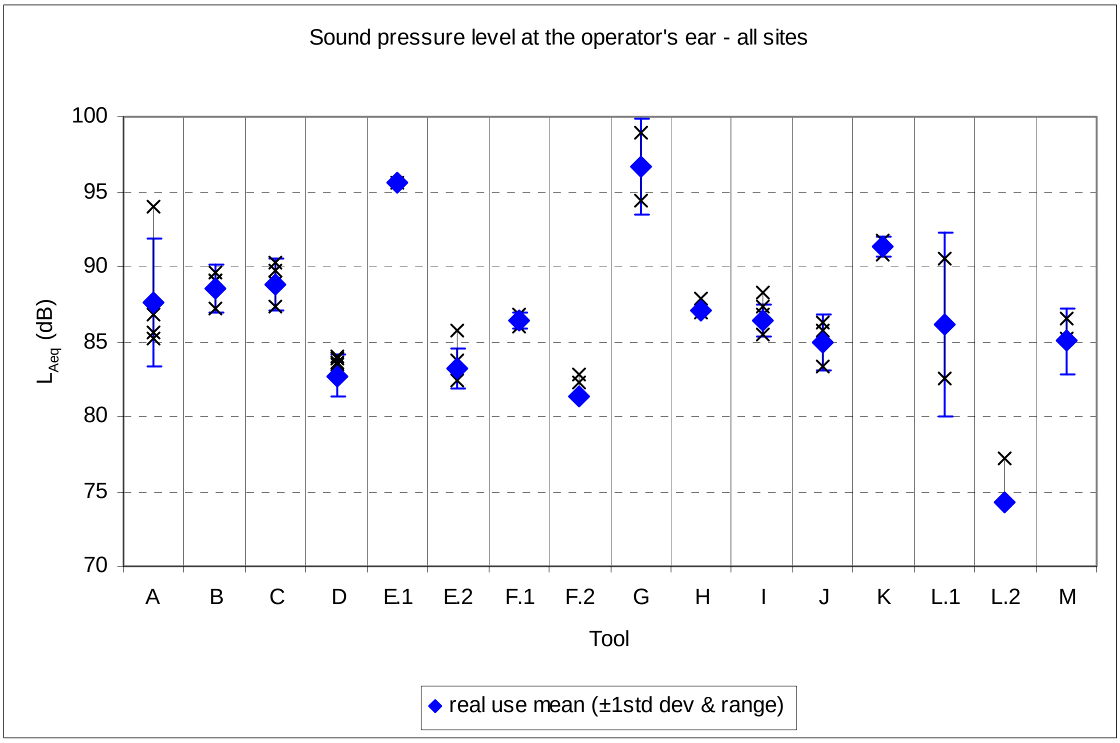


Figure 10. Sound pressure level at the operator's ear, all sites

5.2 DECLARED EMISSION, MEASURED EMISSION AND IN REAL USE RESULTS

Both the pneumatic and electric tool test codes require that the continuous equivalent sound pressure level at the operators ear or at the workstation, L_{pA}, is declared independently from the sound power level of the tool. The declared sound pressure level at the operator's ear, or the emission sound pressure level at the workstation (as referred to in the laboratory test codes), L_{pA}, is in the case of all 13 tools assumed to be equal to the surface sound pressure level as measured when determining the sound power level of the tools. Table 8 and Figures 11a and 11b show the declared workstation emission values, those measured by HSL and the mean sound pressure level from the five sites visited. Table 8 also shows verification of both the manufacturer's declared emissions and the HSL measured emission against the in real use data. Verification has been carried out in accordance with BS EN ISO 4871:1997 [16].

Table 8. Sound pressure levels at the operator's ear: declared, laboratory, in real use

Tool	Declared emission[1]		Measured emission[2]		Real use emission (sites mean)[3]		Verified	
	L_{pA}	K_{pA}	L_{pA}	K_{pA}	L'_{pA}	Std dev	Real use to declared	Real use to measured
A	79	3*	81.7	3.0	87.6	4.27	No	No
B	78	3*	83.6	3.0	88.5	1.58	No	No
C	78	3*	82.9	3.0	88.8	1.77	No	No
D	80	3*	74.1	3.0	82.7	1.43	Yes	No
E.1	72[+]	2*	88.9	3.0	95.7	-	No	No
E.2			77.7	3.0	83.2	1.37	No	No
F.1	82	3*	81.1	3.0	86.4	0.52	No	No
F.2			77.0	3.0	81.4	-	Yes	No
G	84.6	2*	87.4	2.0	96.7	3.18	No	No
H	-	-	80.6	2.0	87.0	0.05	No	No
I	-	-	79.6	3.0	86.4	1.04	No	No
J	79	3*	79.3	3.0	84.9	1.87	No	No
K	-	-	81.8	2.0	91.3	0.66	No	No
L.1	71	± 3	74.7	3.0	86.2	6.12	No	No
L.2			68.4	3.0	74.3	-	No	No
M	73.4	2*	76.8	2.0	85.1	2.19	No	No

*These values have been estimated in accordance with the relevant method quoted and assume a *K* value has not already been included in the declared emission.
[+]This value has been estimated based on the declared L_{WA}-13dB. It assumes a measurement surface area of 20m^2.
[1]This value is an average of 5 measurements at 5 locations, 1m from the tool
[2]This value is an average of 5 measurements at 5 locations, 1m from the tool
[3]This value is an average measured at the operator's ear.

Reminder: E.1 and F.1 refer to the attachment of a hose and dust bag; E.2 and F.2 refer to the use of a silenced exhaust; L.1 is the use of the tool without the hose sleeve over the airline and L.2 is with the hose sleeve over the airline.

Figure 11a shows that a strong relationship is apparent between the HSL measured emission and the in real use emission data. The in real use data was on average 6.9 ± 2.0 dB(A) higher than the HSL measured emission. The range was from 4.4 to 11.5 dB(A). This explains why, although the relationship between the two data sets is strong, the measured emissions are not verified against the in real use data. For the verification process, $L_{real\ use} \leq L_{measured} + K_{measured}$. With the lower limit of the range at 4.4 dB(A), this is greater than the 3 dB(A) K_{pA} so all measured emissions will underestimate the in real use emission in this case.

The relationship between the declared emission and the in real use emission, shown in Figure 11b, is not as strong. The in real use data was on average 8.7 ± 6.3 dB(A) higher than the declared emission. The range was from –0.6 to 23.7 dB(A). This explains why tools D and F.2 are verified; $L_{real\ use} \leq L_{declared} + K_{declared}$. In 14 out of 16 cases, the declared emission underestimates the in real use data.

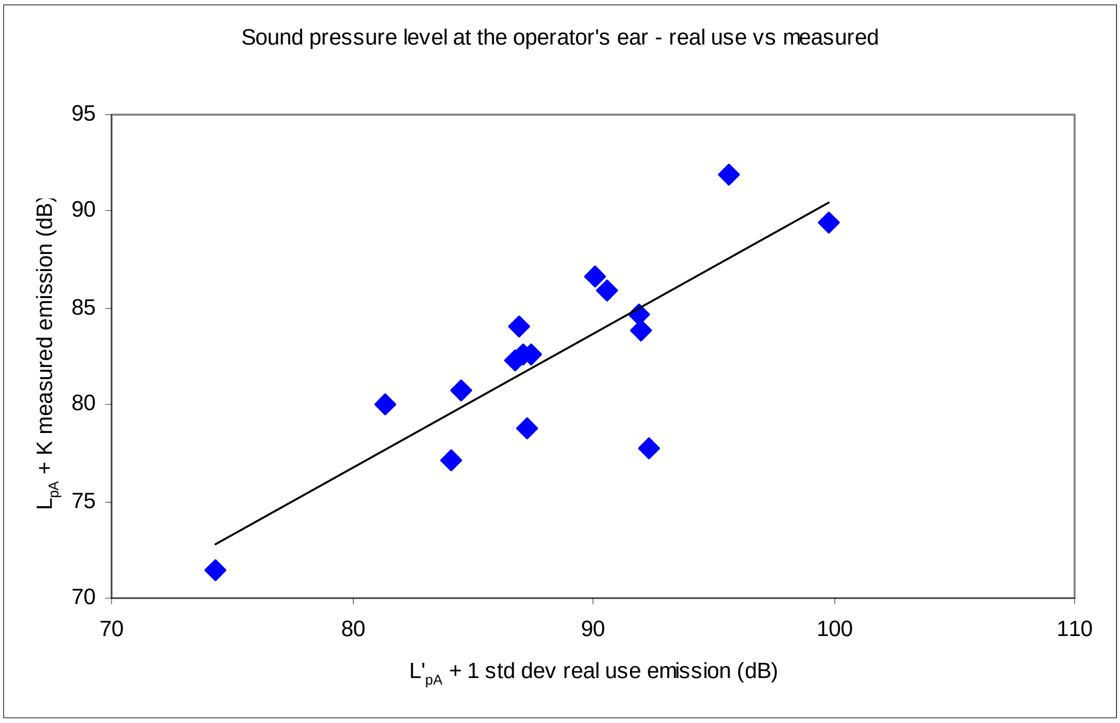


Figure 11a. Sound pressure level at the operator's ear – real use vs measured

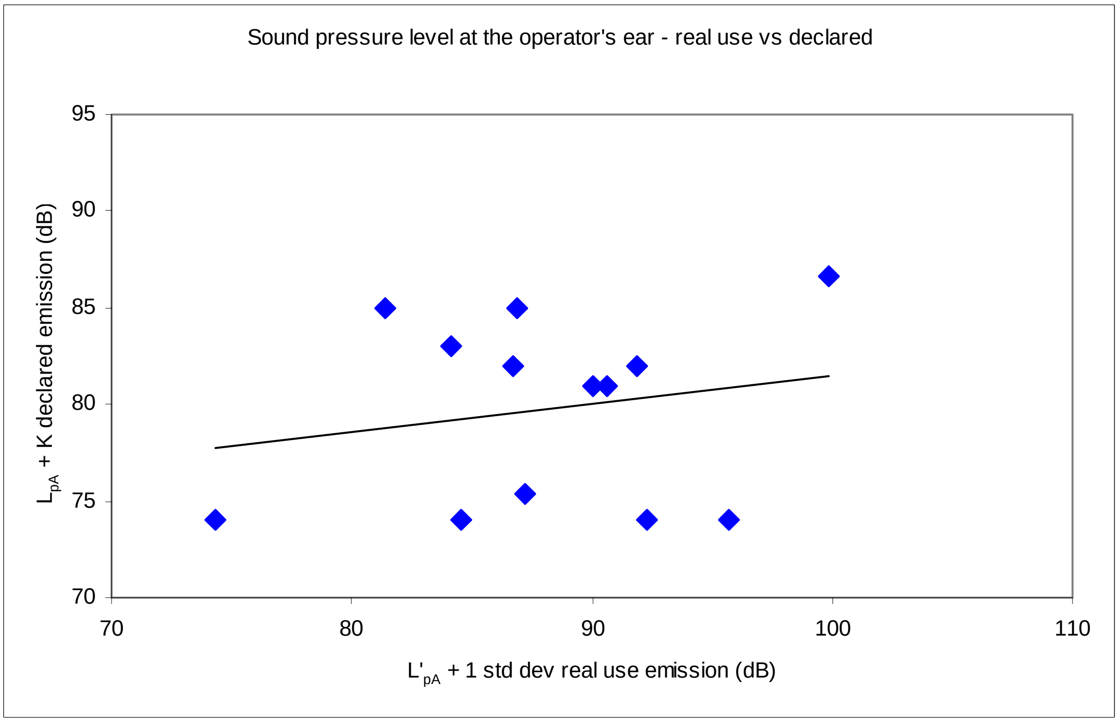


Figure 11b. Sound pressure level at the operator's ear – real use vs declared

Figure 12 shows the real use L'_{pA} emission results against the standard deviation of the measurement. Displaying the data in this way highlights the grouping of the tools. The majority of the tools lie between approximately 80dB and 90dB L'_{pA}. Similar to Figure 7, tool L.2 is identified as low noise while tools G and E.2 are identified as having higher real use emission values. This confirms the strong relationship between the HSL measured emission and the real use emission data.

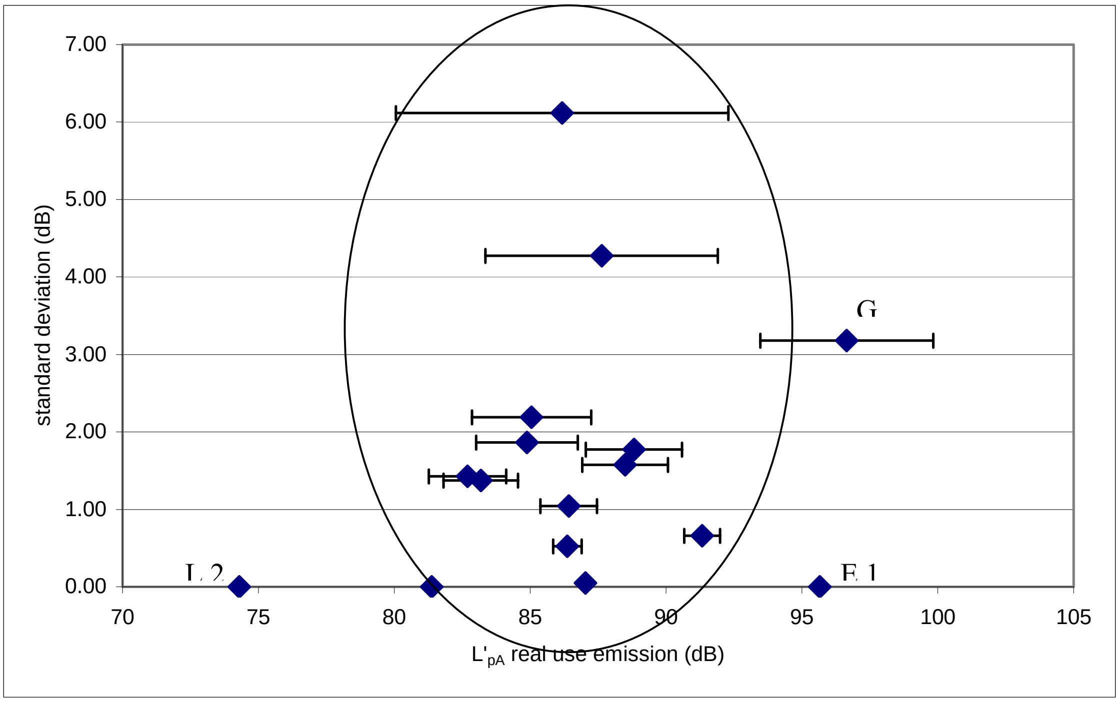


Figure 12. L'$_{pA}$ real use emission vs standard deviation

5.3 MEASUREMENT AT OPERATOR'S EAR: LABORATORY VS REAL USE

Further to Section 3.1.2.2 (Electric tools test codes, emission sound pressure levels), during laboratory testing, additional measurements for the four electric tools were made at a distance of 0.65m above the geometric centre of the tool (1.65m above the reflecting plane). This distance was chosen as representing the approximate location of the operator to the tool when using the tool. The results for these measurements are shown in Table 9 and Figure 13 alongside the declared and measured emissions, both of which are and average of 5 measurements at 5 locations, 1m from the tool, and the mean real use emission, measured at the operator's ear.

Table 9. Additional L_{pA} measurements for electric tools

Tool	Declared emission		Measured emission		Real use emission		Measured emission @ 0.65 m	
	L_{pA}	K_{pA}	L_{pA}	K_{pA}	L'_{pA}	Std dev	L_{pA}	Std dev
G	84.6	2*	87.4	2.0	96.7	3.18	91.5	0.55
H	-	-	80.6	2.0	87.0	0.05	83.5	0.32
K			81.8	2.0	91.3	0.66	83.6	0.00
M	73.4	2*	76.8	2.0	85.1	2.19	80.4	0.06

*These values have been estimated in accordance with the relevant method quoted and assume a *K* value has not already been included in the declared emission.

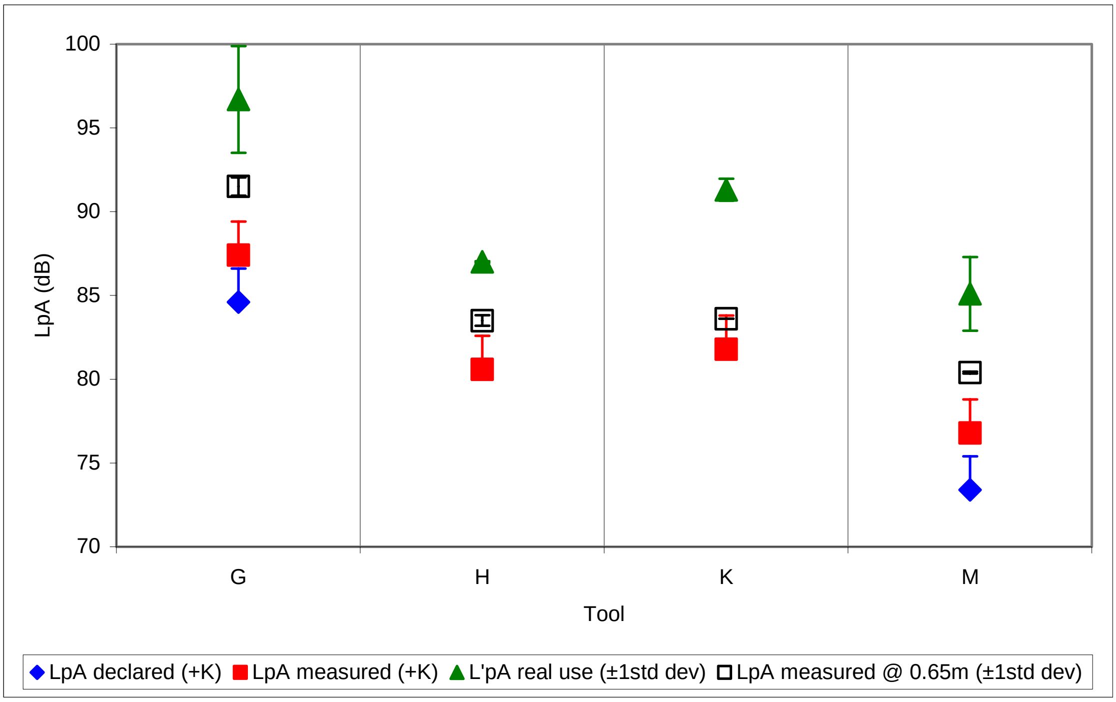


Figure 13. Additional L_{pA} measurements for electric tools

The trend indicates that measurement at the location of 0.65m above the geometric centre of the tool is more representative of the operator's exposure during real use compared with the measured L_{pA}. However, real use values are still underestimated by between 3.9dB and 8.9dB.

6 EMISSION VALUES AS AN INDICATOR OF RISK

As outlined in Section 1.1, manufacturers have a duty to declare airborne noise information relating to their tools. The safety standards or test codes used to obtain such information instruct manufacturers as to which information they must declare and how. In order that emission data may be used in risk assessment, manufacturers need to adhere to these instructions, and those of the Safety Regulations, and declare noise information in a consistent fashion. For example, declaration of L_{pA} for every tool will allow for verification of a low noise tool design and will additionally enable purchasers and users of machinery to make informed choices regarding the safety of a potential purchase. As has been demonstrated in Table 2, such consistency across all tools is not always available.

The results from this study indicate that use of the manufacturer's declared emissions in risk assessment will allow the end user to identify low and high noise designs. However, as Figure 14 shows, the declared emission is not necessarily suitable for the estimation of exposure. Figure 14 shows the difference between the real use emission (L'_{pA}) and the declared emission (L_{pA}). Points below the value of 0 indicate where emission data over estimated field data. Points above the value of 0 indicate where emission data under estimated field data.

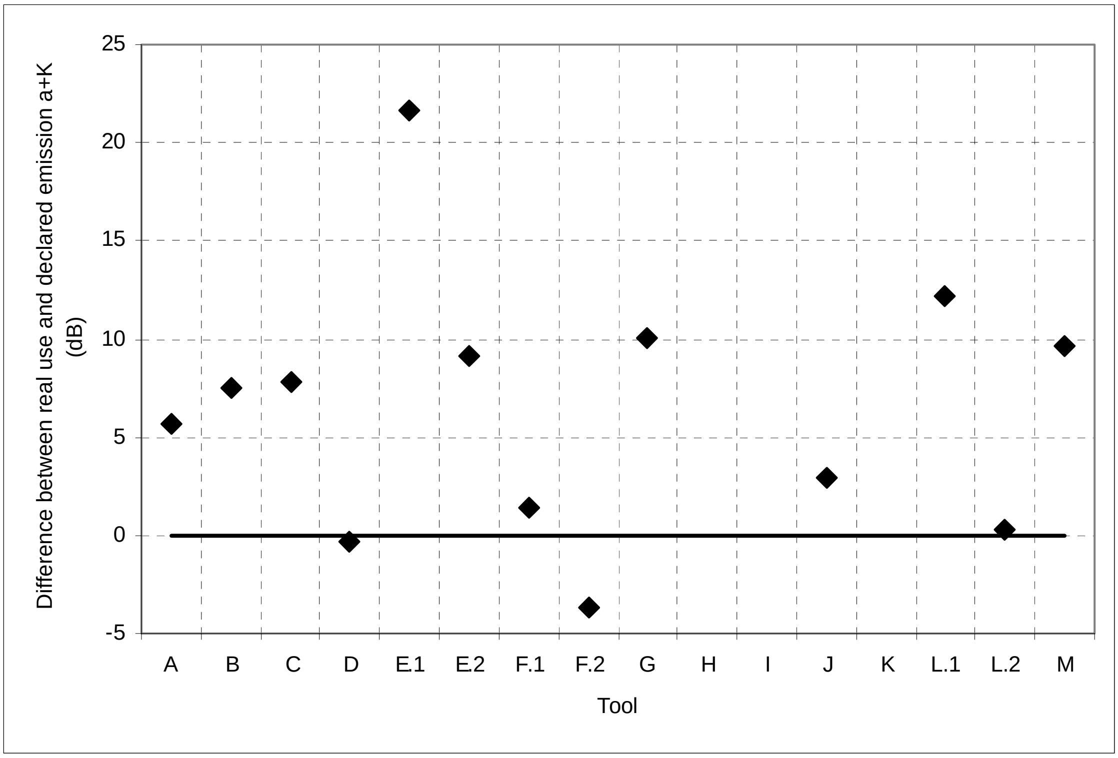


Figure 14. Difference between real use measurement and declared emission a+K (dB)

From Section 5.2, the real use measurement was shown to be on average 8.7 ± 6.3 dB(A) higher than the declared emission, in the range of –0.6 to 23.7 dB(A) (tools F.2. and E.1. respectively). Together with Figure 14, this shows that whilst the use of the manufacturer's declared sound pressure level as an indicator of exposure may not always be sufficient, it can indicate relative risk between tools. This confirms the results in Table 8.

7 SUMMARY

Airborne noise emission data, required by the Supply of Machinery (Safety) Regulations 1992 [3] (SM(S)R) as amended, varied greatly between manufacturers and between different tools supplied by the same manufacturer. While the regulations and related transposed standards for the family of tools under consideration are clear about declaration requirements, the method of declaration and the quality of data supplied is not always consistent or transparent, making it difficult to compare machines.

Where the manufacturer had stated the test code used, this was also used for the laboratory measurement. In the case of the electrically powered tools supplied, this meant using the partially superseded EN 50144 series of standards [7] [8] [9]. In the case of the pneumatic tools, historical development of the standard from the (CAGI-)PNEUROP trade association publication [14] to the present BS EN ISO 15744 [5] international standard led to a lack of clarity regarding inclusion or otherwise of an uncertainty value associated with the declared emission.

Where declared sound pressure level (L_{pA}) emission information was available, there was some correlation between manufacturers' declared emissions and the results from laboratory measurement – emission data for 5 out of 13 tools were verified. Where declared sound power level (L_{WA}) information was available, an additional sixth tool was also verified. This anomaly arose due to the differences in calculation of L_{WA} for electric and pneumatic tools that require the shape of the measurement surface to be taken into account. Although identical microphone locations are used, a 2dB(A) difference in sound power level can be attributed to the calculation of L_{WA} alone and has nothing to do with the actual noise emission from the tool.

At the time of writing, the EN 50144 safety standard series had been partially superseded by the EN 60745:2003 safety standard series [10] [11] (which mirrors the noise test code in ISO 15744 [5]), with a 2006 revision also due. It should be noted that comparison of L_{WA} emission values obtained from EN 50144 and ISO 15774 cannot be drawn on a like-for-like basis due to the 2dB(A) difference obtained through calculation. L_{pA} values are unaffected.

A fundamental difference in the testing of pneumatic and electric powered tools is that the electric tool tests are free running whereas the pneumatic tool tests are under load and require an operator, a defined work piece and work pattern; pneumatic polishers are an exception as they are tested free running. Testing the electric tools to the pneumatic standard, i.e. under load and with an operator, revealed an overall decrease in noise emission from the tool. This is not reflective of the noise emission in the workplace. If the declared emissions for electric tools are to be used in risk assessment then the free running test is more appropriate. The loaded test for pneumatic tools is also appropriate.

Standard tests have the potential to put tools in correct order of relative risk. This enables purchasers and users of machinery to identify low noise designs and make informed choices regarding the safety of a potential purchase from a broad range of tools. In practice, standard test results are only acceptable for relative risk if there is consistency in how the emission data are declared. The standard test results are not acceptable for identifying absolute risk.

Comparison of real use (field) measurement data with the manufacturers' declared workstation emission (where available) revealed differences in L_{pA} values ranging from -0.6 to 23.7 dB(A). This indicates that use of the declared L_{pA} emission values in exposure assessment is likely to underestimate the real use workstation emission level. Real use emission was on average 8.7 ± 6.3 dB(A) higher than the declared emission.

8 APPENDIX A – EMISSION TEST RESULTS: SUMMARY

Tool	Type	Action	Power	Declared					Measured						In real use	
				L_{pA} dB	K_{pA} dB	L_{WA} dB	K_{WA} dB	Standard	L_{pA} dB	K_{pA} dB	L_{WA} dB	K_{WA} dB	Standard	Notes	L'_{pA} dB	Std Dev
A	sander	random orbital	pneumatic	79	3*	-	-	SPL @ 1m PN8NTC1.2	81.7	3.0	92.7	3.0	BS EN ISO 15744:2002	Hose & bag	87.6	4.27
B	sander	random orbital	pneumatic	78	3*	91	3*	SPL/SWL @ 1m	83.6	3.0	94.5	3.0	BS EN ISO 15744:2002	Silenced exhaust	88.5	1.58
C	sander	random orbital	pneumatic	78	3*	91	3*	SPL/SWL @ 1m	82.9	3.0	93.8	3.0	BS EN ISO 15744:2002	Silenced exhaust	88.8	1.77
D	sander	orbital	pneumatic	80	3*	93	3*	SPL/SWL @ 1m	74.1	3.0	85.0	3.0	BS EN ISO 15744:2002	Silenced exhaust	82.7	1.43
E.1	sander	random orbital	pneumatic	72[+]	2*	85	± 2	CAGI-PNEUROP ISO 3744	88.9	3.0	99.9	3.0	BS EN ISO 15744:2002	Hose & bag	95.7	-
E.2	"	"	"						77.7	3.0	88.7	3.0	BS EN ISO 15744:2002	Silenced exhaust	83.2	1.37
F.1	sander	orbital	pneumatic	82	3*	-	-	EN ISO 15744	81.1	3.0	92.0	3.0	BS EN ISO 15744:2002	Hose & bag	86.4	0.52
F.2	"	"	"						77.0	3.0	87.9	3.0	BS EN ISO 15744:2002	Silenced exhaust	81.4	-
G	sander	random orbital	electric	84.6	2*	97.5	2*	BS EN ISO 50144-2-4:1999	87.4	2.0	100.4	2.0	BS EN 50144-2-4:2000	With bag	96.7	3.18
H	sander	orbital	electric	-	-	-	-	No data available.	80.6	2.0	93.5	2.0	BS EN 50144-2-4:2000	No attachments	87.0	0.05
I	sander	random orbital	pneumatic	-	-	-	-	80dB(A) given. Unqualified.	79.6	3.0	90.6	3.0	BS EN ISO 15744:2002	Silenced exhaust	86.4	1.04
J	polisher	random orbital	pneumatic	79	3*	92	3*	SPL/SWL @ 1m	79.3	3.0	90.3	3.0	BS EN ISO 15744:2002	Silenced exhaust	84.9	1.87
K	polisher	angle	electric	-	-	-	-	88.7dB & EN 50144 given. Unqualified.	81.8	2.0	94.8	2.0	BS EN 50144-2-3:2002	No attachments	91.3	0.66
L.1	polisher	angle	pneumatic	71	± 3	-	-	PN8NTC1.2	74.7	3.0	85.7	3.0	BS EN ISO 15744:2002	No hose sleeve	86.2	6.12
L.2	"	"	"						68.4	3.0	79.4	3.0	BS EN ISO 15744:2002	With hose sleeve	74.3	-
M	sander	orbital	electric	73.4	2*	-	-	EN 50144	76.8	2.0	89.8	2.0	BS EN 50144-2-4:2000	Without bag	85.1	2.19

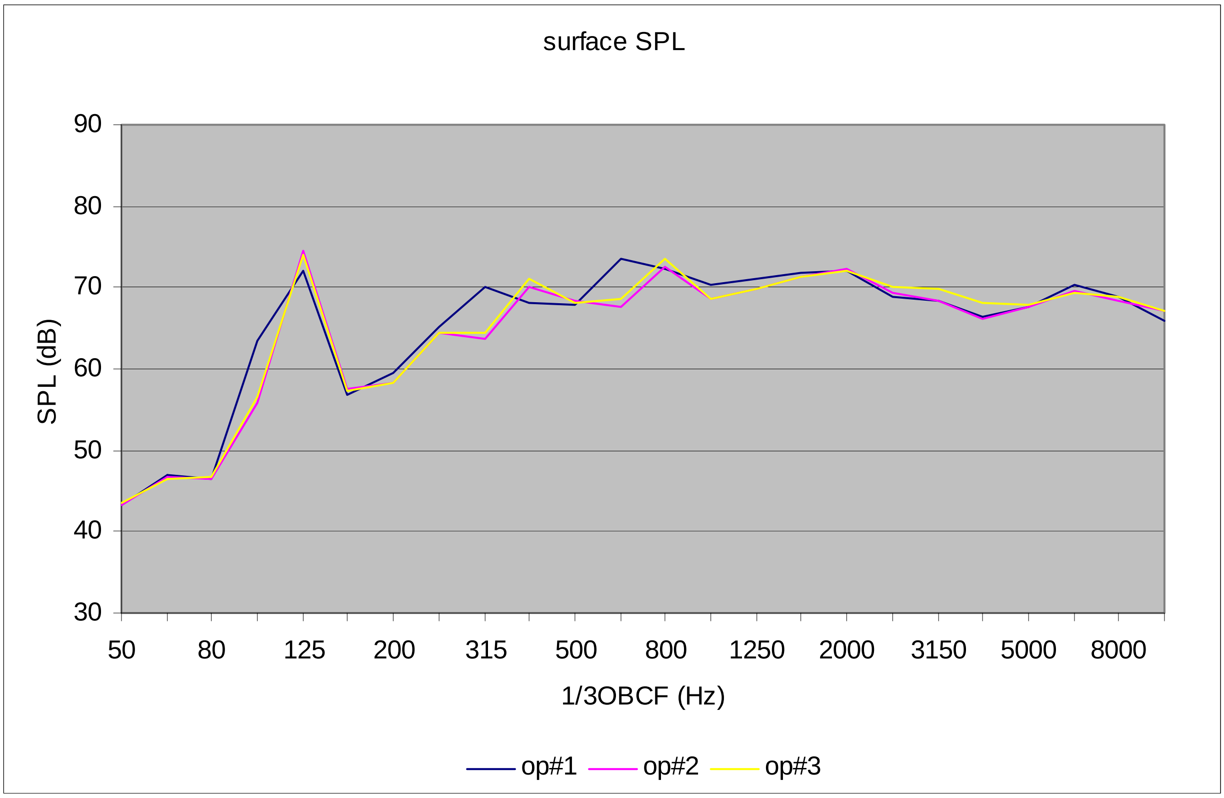
*These values have been estimated in accordance with the relevant method quoted and assume a *K* value has not already been included in the declared emission.

[+]This value has been estimated based on the declared L_{WA}-13dB. It assumes a measurement surface area of 20m^2.

9 APPENDIX B – EMISSION TEST RESULTS: DETAIL

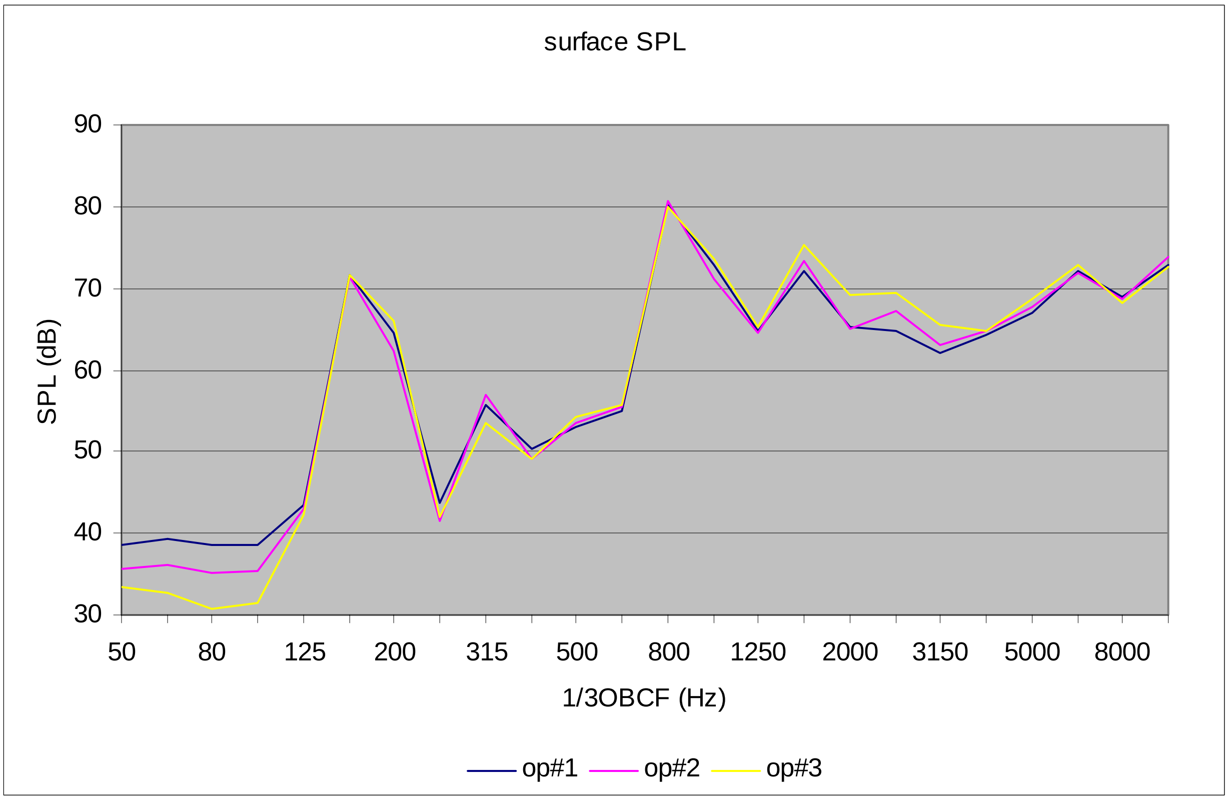
Tool A

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	93.0	82.0	85.7
2nd run	92.4	81.4	85.7
3rd run	92.8	81.8	85.6
	92.7	**81.7**	**85.7**



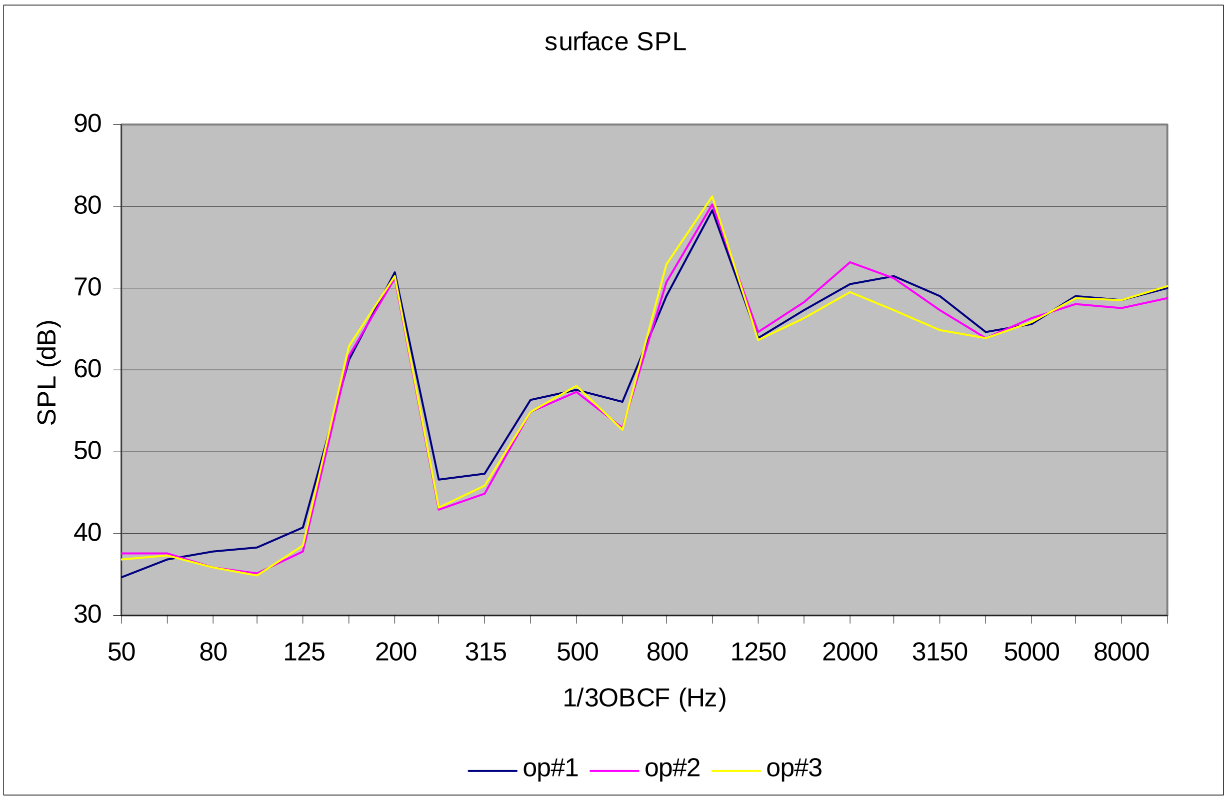
Tool B

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	94.1	83.1	86.2
2nd run	94.5	83.5	85.7
3rd run	95.0	84.0	88.3
	94.5	**83.6**	**88.3**



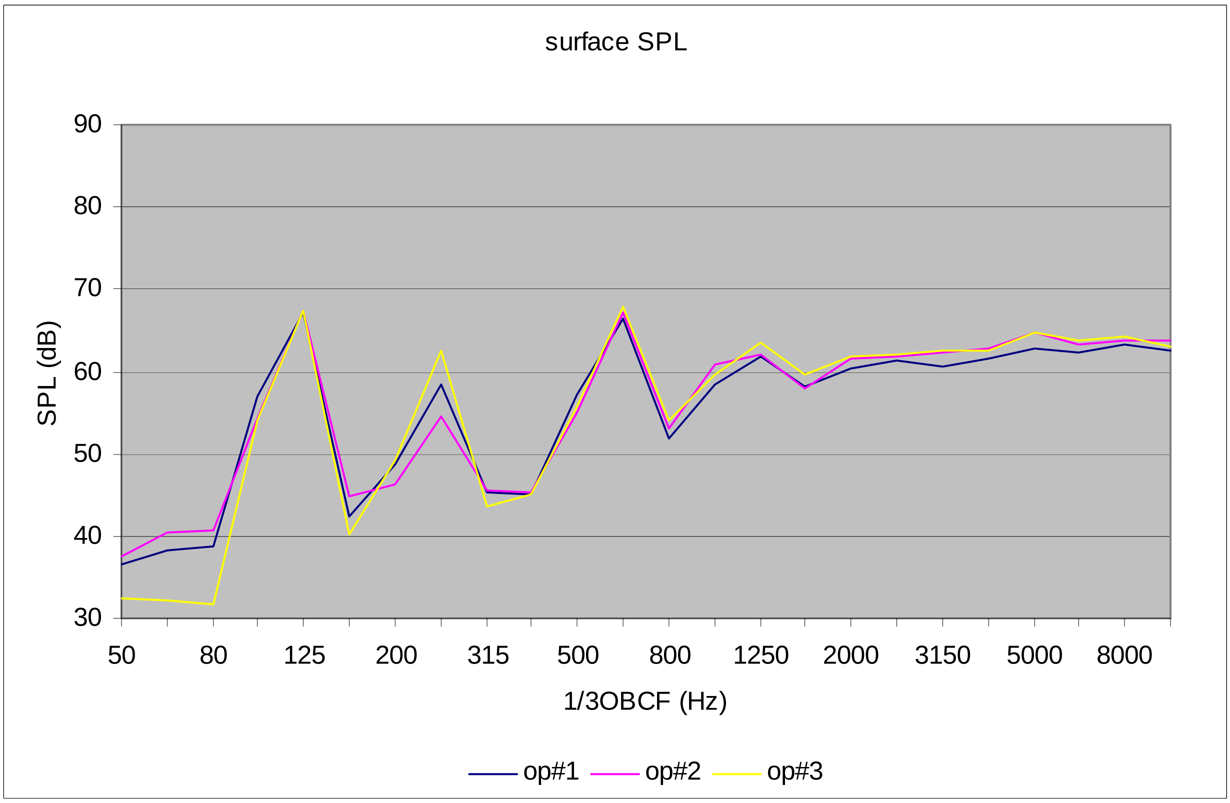
Tool C

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	93.5	82.5	86.6
2nd run	93.9	82.9	87.8
3rd run	94.1	83.1	87.5
	93.8	**82.9**	**87.8**



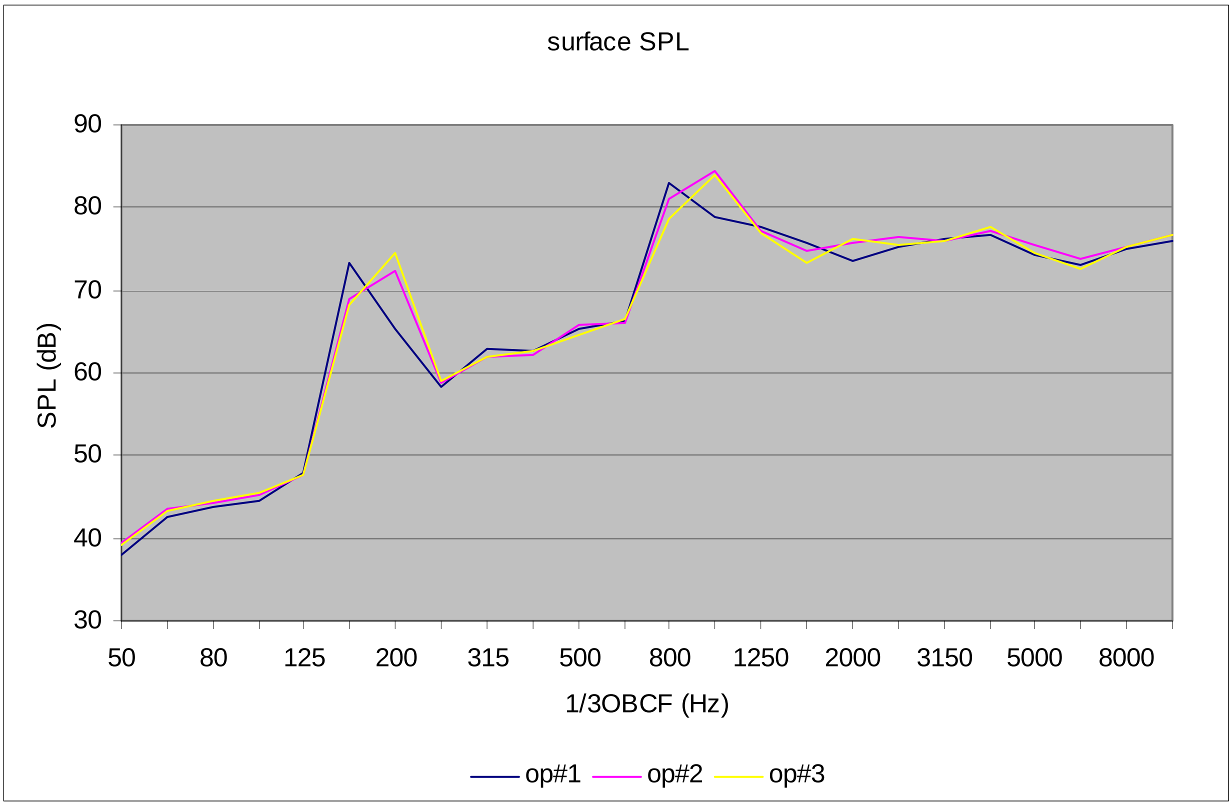
Tool D

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	84.2	73.2	75.9
2nd run	85.3	74.3	76.7
3rd run	85.5	74.5	78.0
	85.0	**74.1**	**78.0**



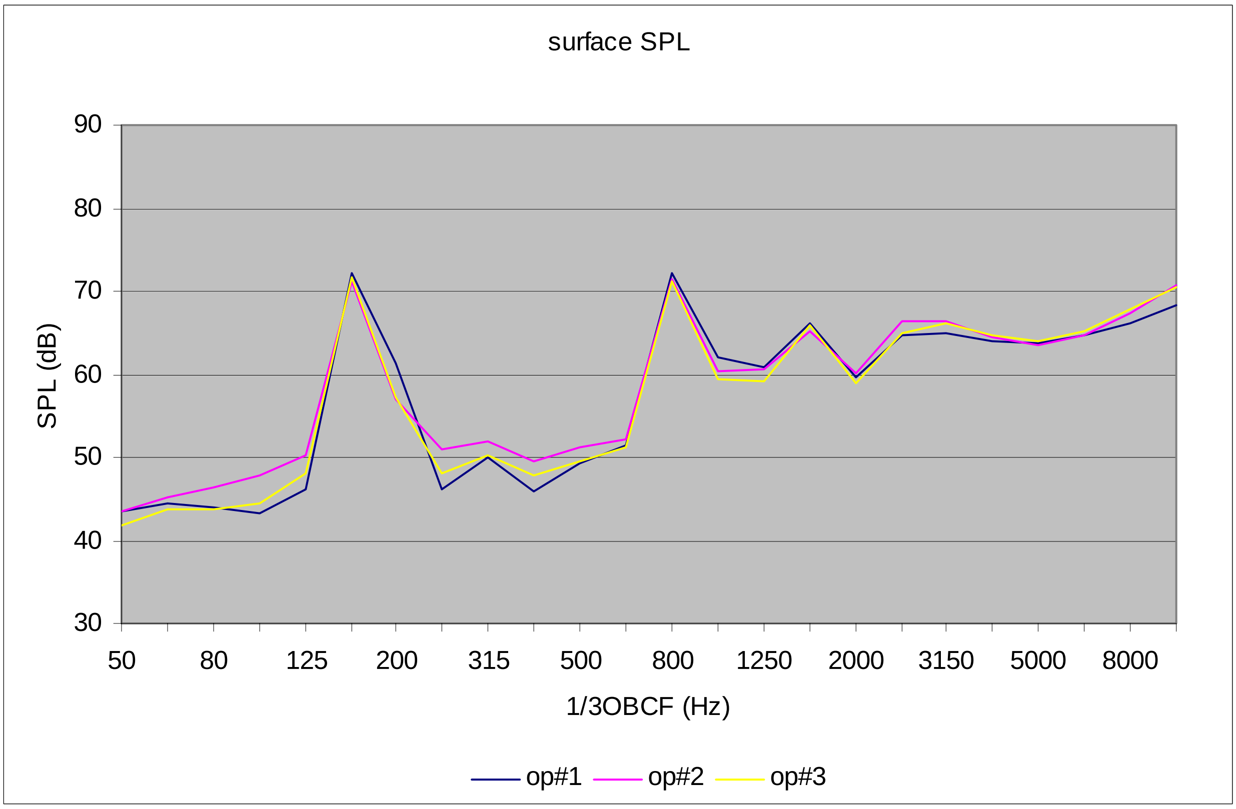
Tool E.1

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	99.4	88.4	91.4
2nd run	100.5	89.5	92.2
3rd run	99.9	88.9	93.1
	99.9	**88.9**	**93.1**



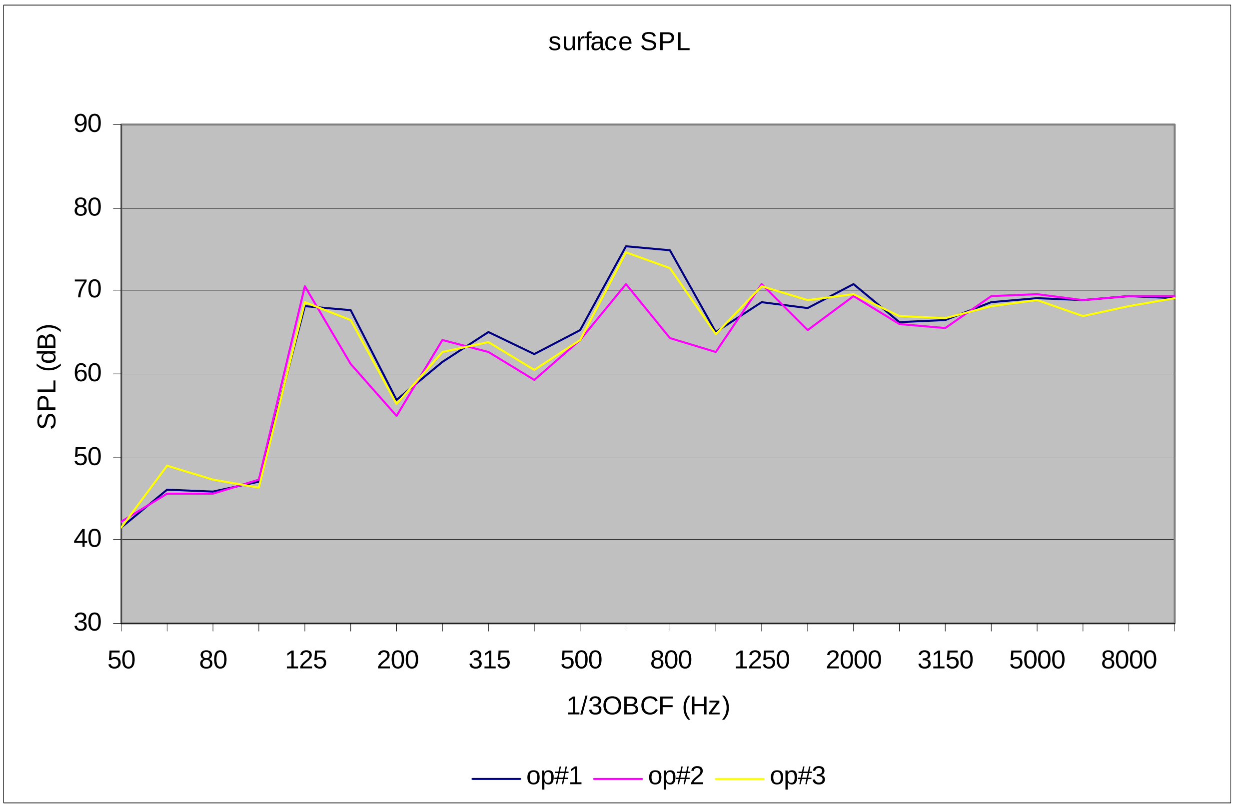
Tool E.2

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	88.3	77.3	79.9
2nd run	88.8	77.8	80.8
3rd run	89.0	78.0	82.2
	88.7	**77.7**	**82.2**



Tool F.1

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	92.7	81.7	85.2
2nd run	91.0	80.0	83.6
3rd run	92.2	81.2	86.4
	92.0	**81.1**	**86.4**



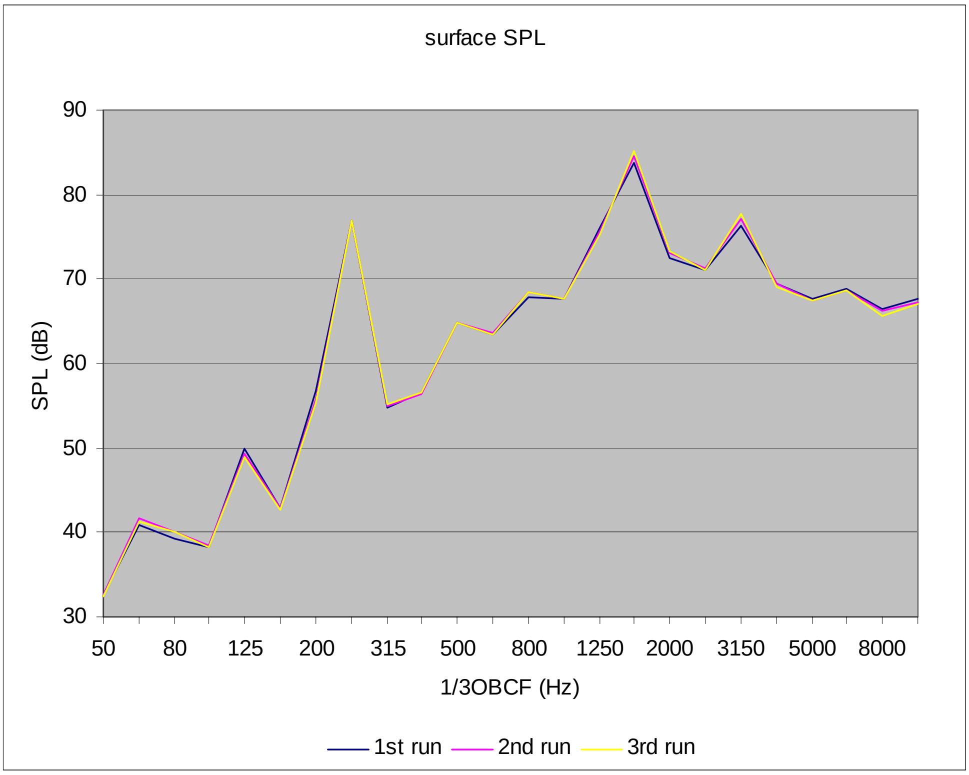
Tool F.2

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	89.3	78.3	81.0
2nd run	87.1	76.1	78.4
3rd run	87.3	76.3	78.9
	87.9	**77.0**	**81.0**

Tool G

	L_{Aeq} 1st run	2nd run	3rd run	$L_{Cpk(max)}$		
mic pos 1	84.5	85.3	85.9	97.2	97.5	98.0
mic pos 2	87.8	88.5	88.5	99.4	99.0	99.2
mic pos 3	87.2	87.4	87.6	99.1	98.9	98.7
mic pos 4	85.5	85.7	86.2	96.4	97.1	97.7
mic pos 5	88.4	89.1	89.7	98.2	98.5	98.3
oper.ear	91.2	91.1	92.1	100.6	101.1	102.3
L_p	86.9	87.5	87.8			
bkg check	valid	valid	valid			
L_W	99.9	100.5	100.8			

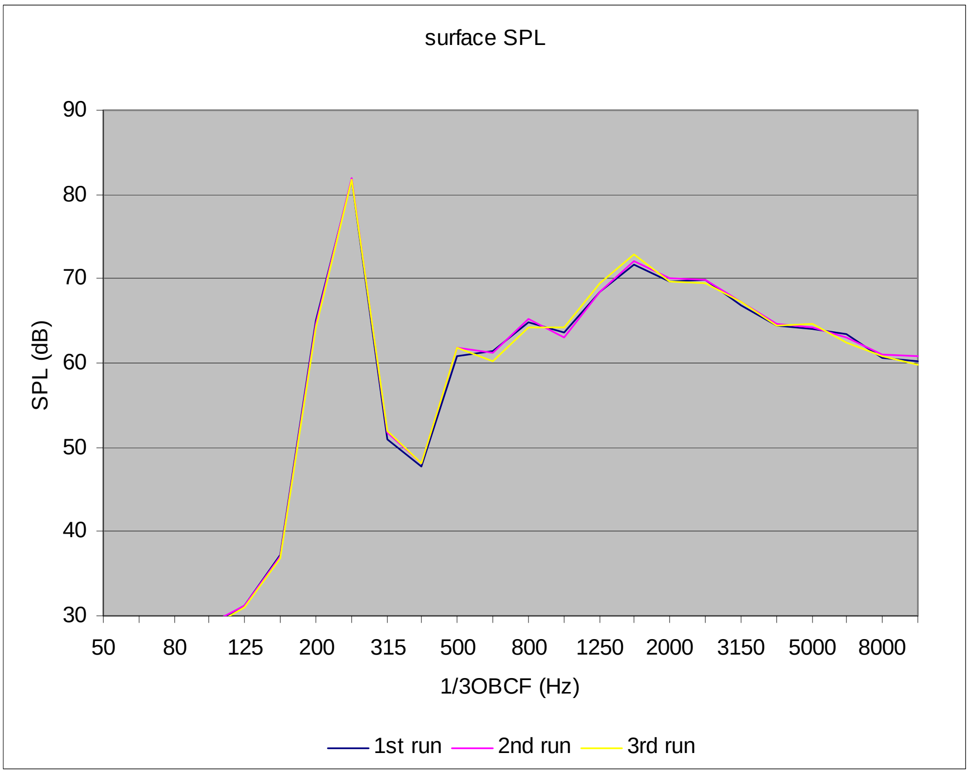
L_{Aeq} bkg	17.3	dB(A)
$L_{Aeq\ tool}$	87.4	dB(A)
$L_{Aeq\ operator\ ear}$	**91.5**	dB(A)
$L_{Cpk(max)}$	**102.3**	dB(C)
L_{WA}	**100**	dB(A)



Tool H

	L_{Aeq} 1st run	2nd run	3rd run	$L_{Cpk(max)}$ 1st run	2nd run	3rd run
mic pos 1	83	80.4	80.5	93.5	93.4	93.5
mic pos 2	83.3	79.1	79.4	93.2	93.4	93.0
mic pos 3	80.3	79.9	80.0	93.5	93.0	93.6
mic pos 4	80.6	80.9	80.9	94.5	94.6	95.0
mic pos 5	79.2	79.1	79.3	92.5	92.4	91.9
oper.ear	83.9	83.4	83.3	96.4	96.3	96.0
L_p	81.6	79.9	80.1			
bkg check	valid	valid	valid			
L_W	94.6	92.9	93.1			

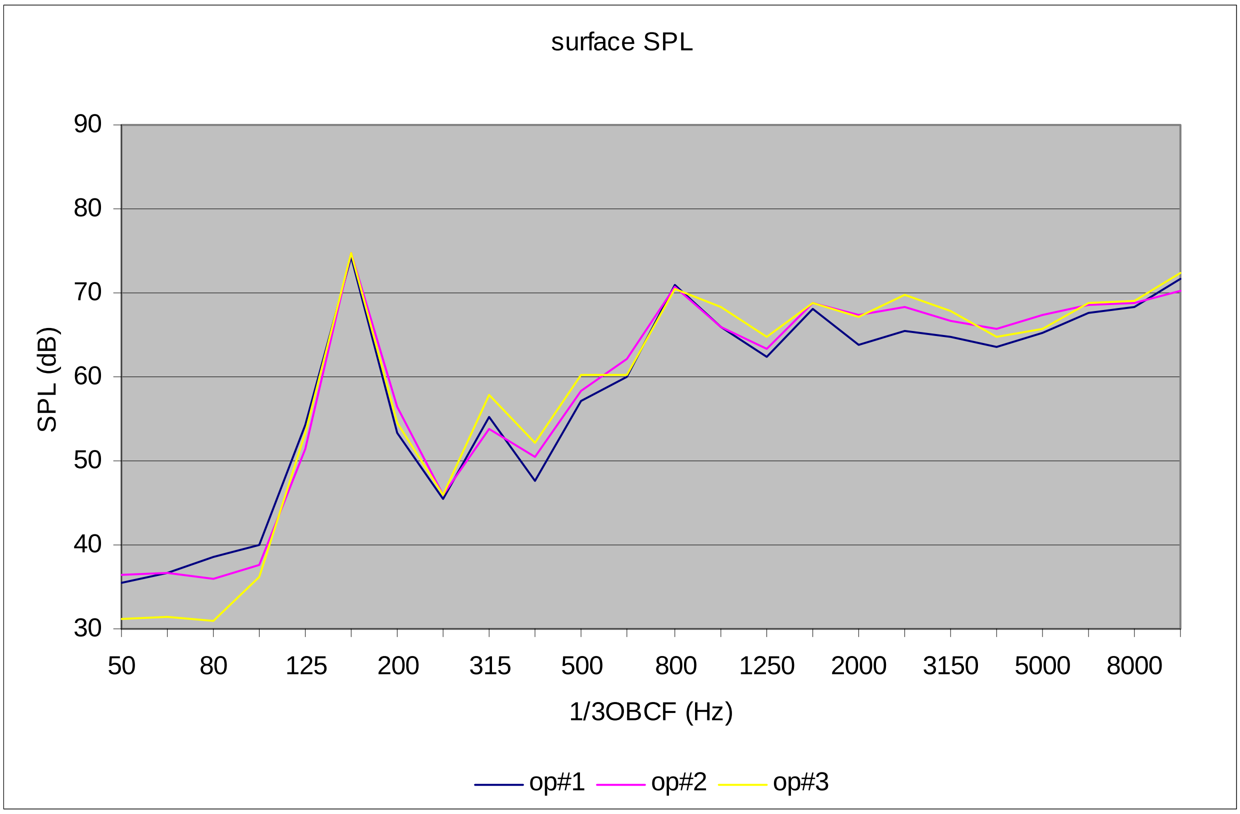
L_{Aeq} bkg	17.6	dB(A)
$L_{Aeq\ tool}$	80.6	dB(A)
$L_{Aeq\ operator\ ear}$	**83.5**	dB(A)
$L_{Cpk(max)}$	**96.4**	dB(C)
L_{WA}	**94**	dB(A)



Tool I

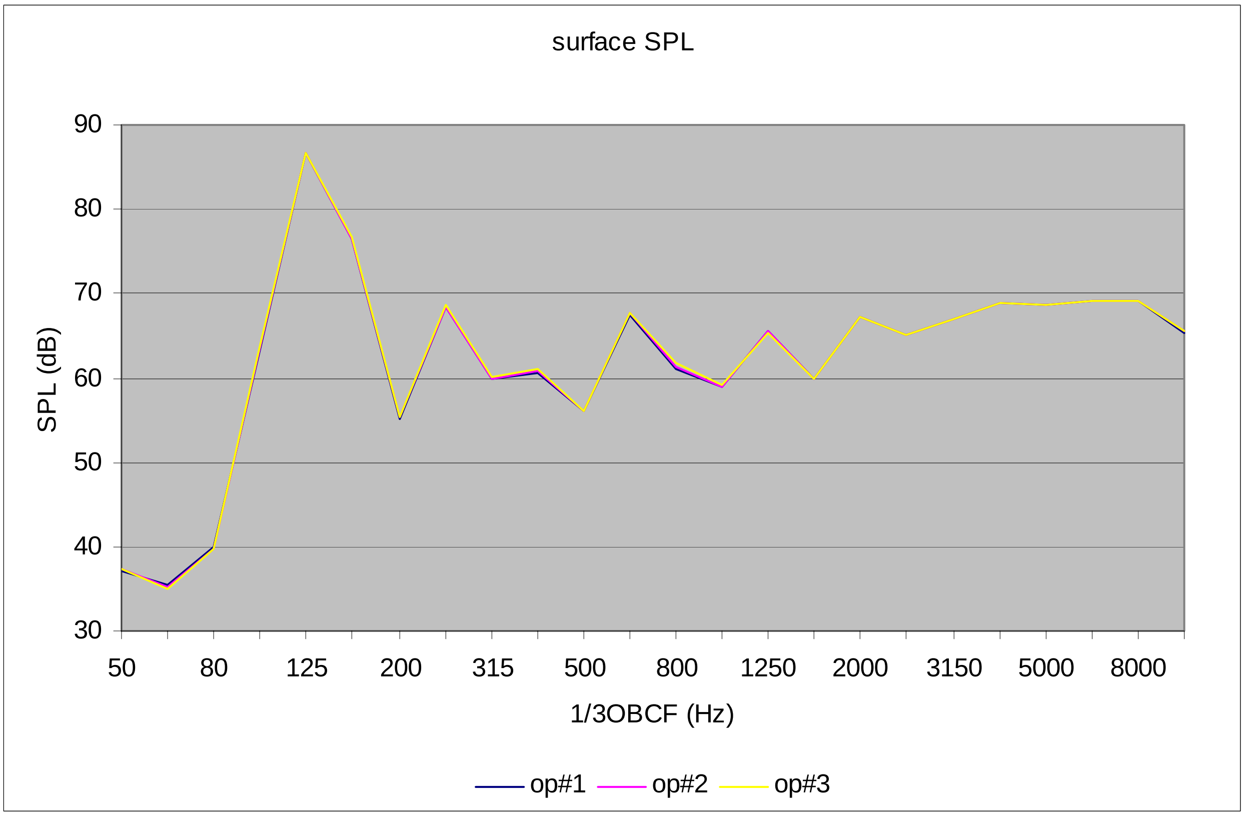
	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	89.9	78.9	82.2
2nd run	90.6	79.6	83.4
3rd run	91.3	80.3	84.1

	90.6	**79.6**	**84.1**



Tool J

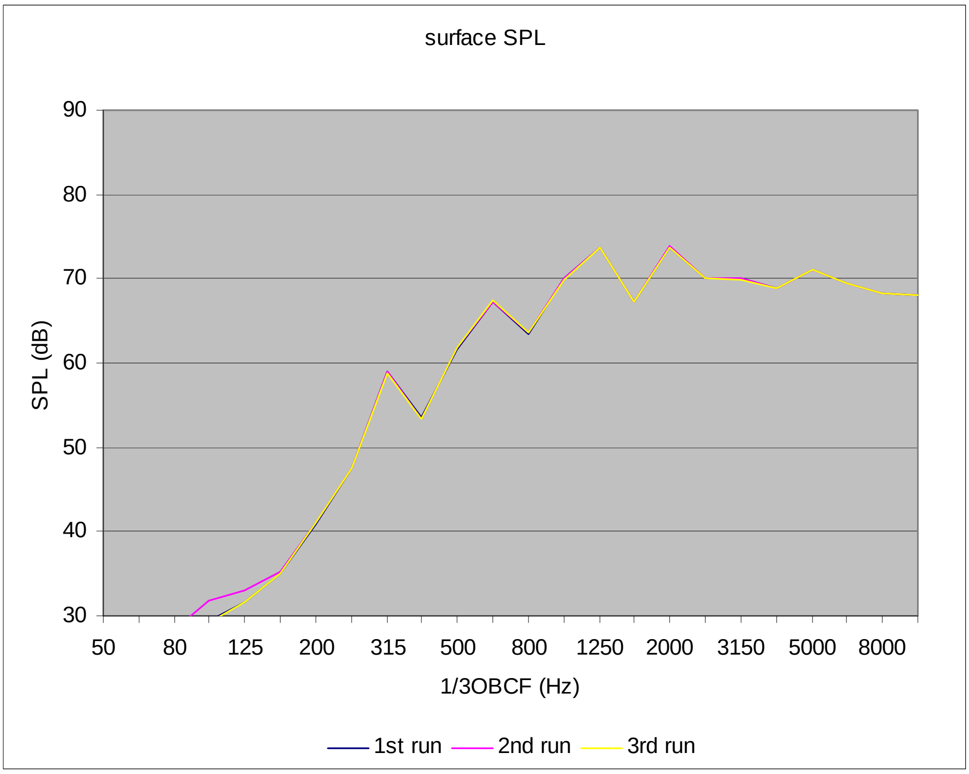
	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	90.3	79.3	89.7
2nd run	90.3	79.3	90.2
3rd run	90.3	79.3	90.5
	90.3	**79.3**	**90.5**



Tool K

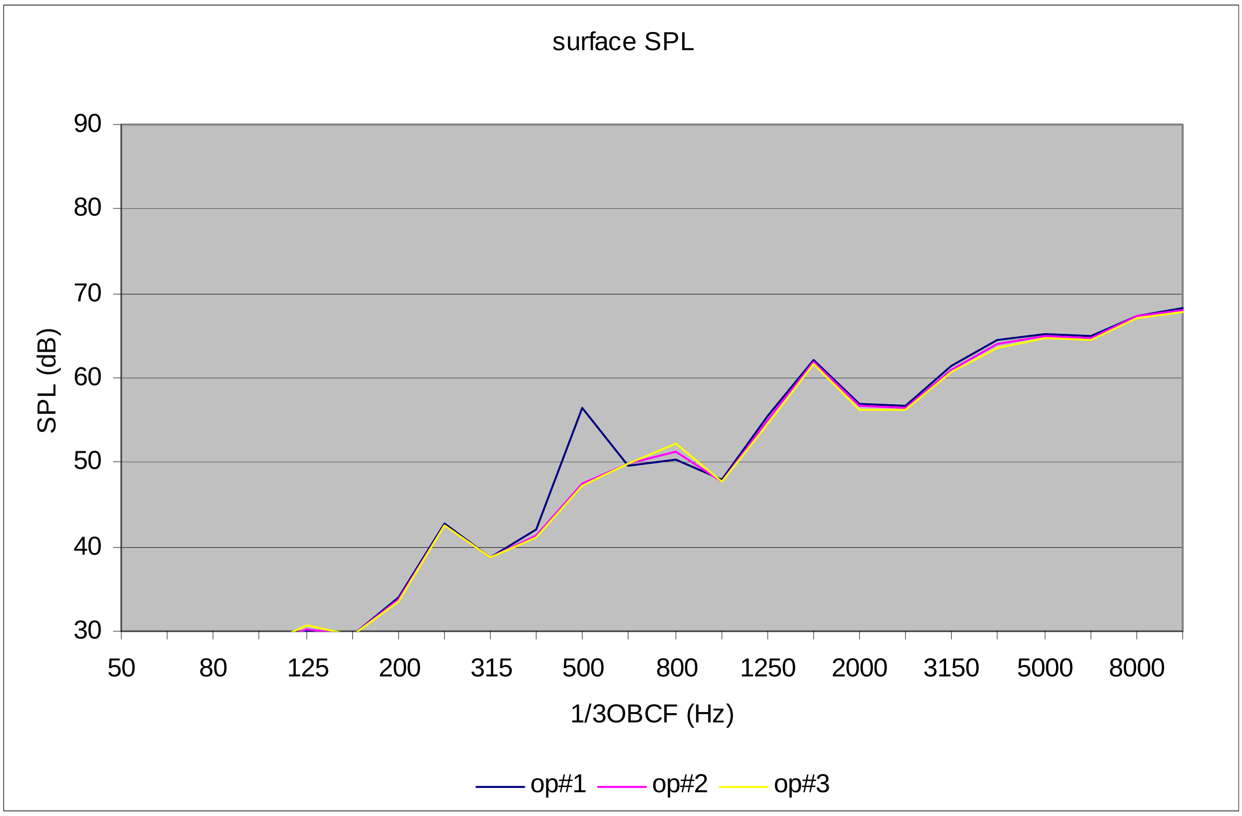
	L_{Aeq} 1st run	2nd run	3rd run	$L_{Cpk(max)}$		
mic pos 1	81.0	80.9	81.0	94.2	93.9	94.4
mic pos 2	81.2	81.2	81.2	94.1	94.7	94.4
mic pos 3	82.7	82.7	82.6	95.3	95.3	94.9
mic pos 4	83.4	83.6	83.4	95.7	96.2	96.4
mic pos 5	79.8	79.9	79.9	93.1	93.3	94.5
oper.ear	83.6	83.6	83.6	96.8	96.7	97.2
L_p	81.8	81.9	81.8			
bkg check	valid	valid	valid			
L_W	94.8	94.9	94.8			

L_{Aeq} bkg	17.9	dB(A)
$L_{Aeq\ tool}$	81.8	dB(A)
$L_{Aeq\ operator\ ear}$	**83.6**	dB(A)
$L_{Cpk(max)}$	**97.2**	dB(C)
L_{WA}	**95**	dB(A)



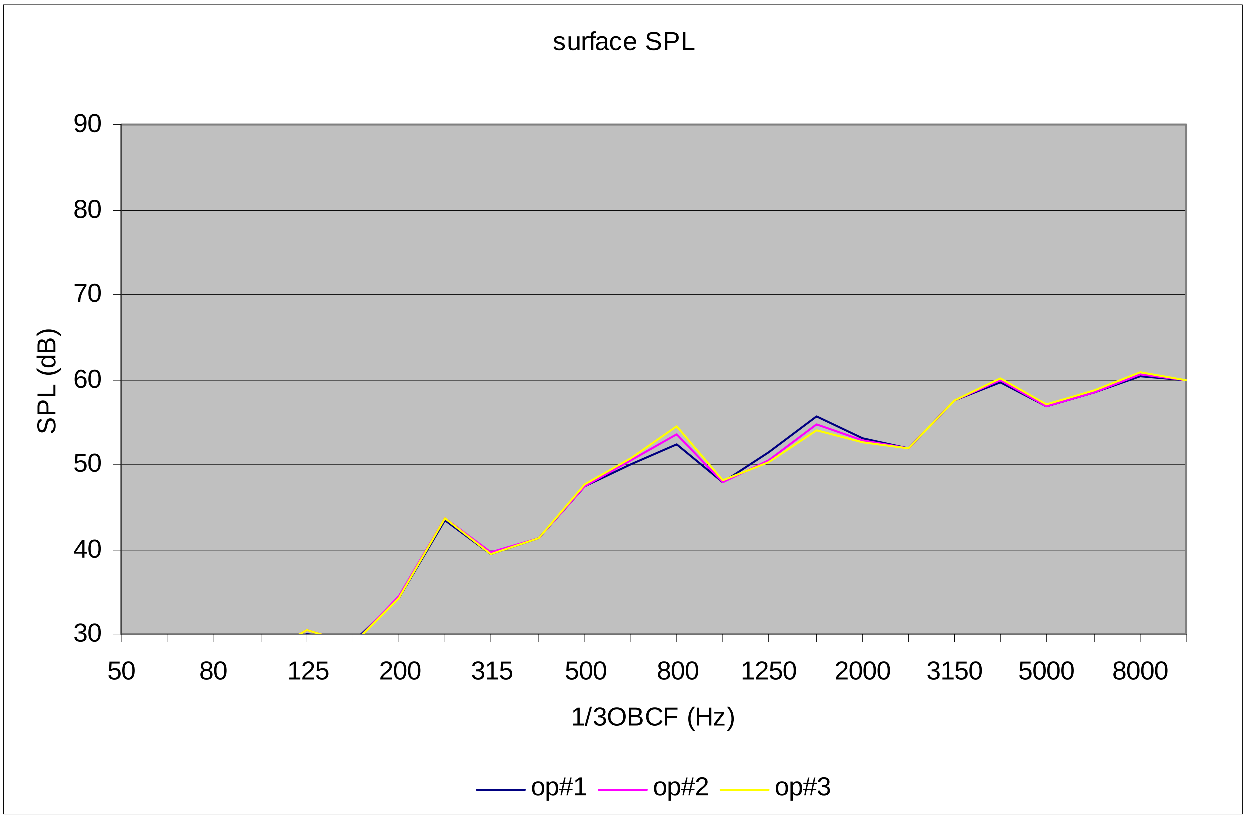
Tool L.1

	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	86.0	75.0	76.7
2nd run	85.7	74.7	76.7
3rd run	85.5	74.5	75.8
	85.7	**74.7**	**76.7**



Tool L.2

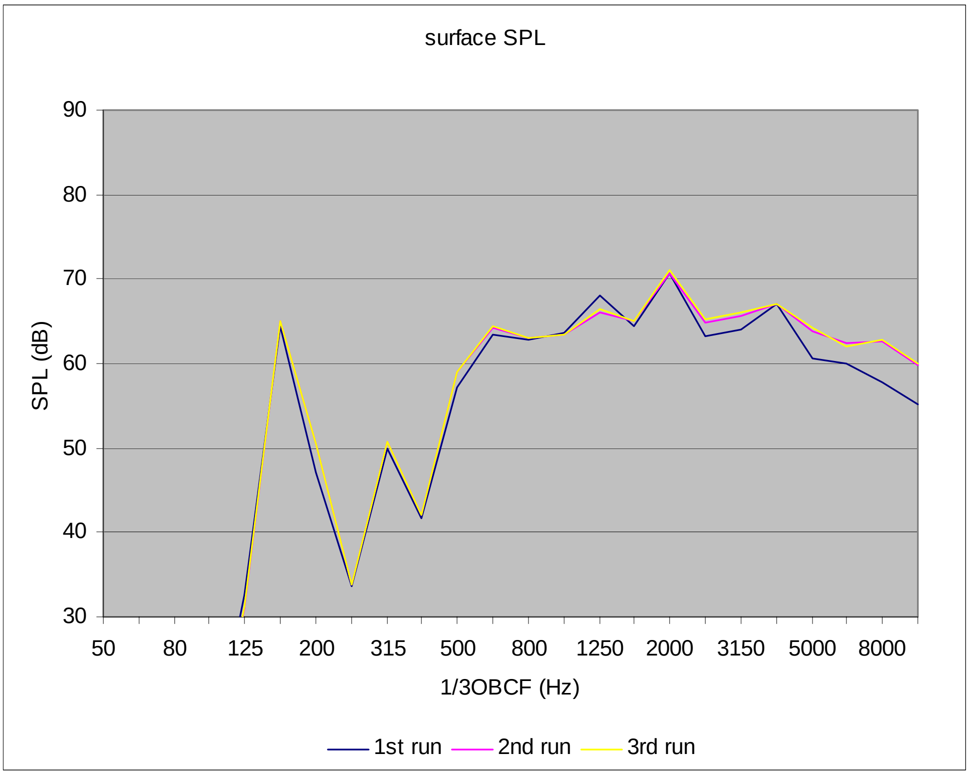
	L_{WA}	L_{pA}	$L_{Cpk(max)}$
1st run	79.4	68.4	69.8
2nd run	79.4	68.4	69.9
3rd run	79.5	68.5	70.1
	79.4	**68.4**	**70.1**



Tool M

	L_{Aeq} 1st run	L_{Aeq} 2nd run	L_{Aeq} 3rd run	$L_{Cpk(max)}$		
mic pos 1	74.1	75.5	75.6	89.5	91.8	91.3
mic pos 2	75.6	76.5	76.5	89.0	90.1	91.0
mic pos 3	77.6	78.0	78.3	90.7	92.5	91.7
mic pos 4	76.4	77.0	77.3	91.9	92.4	92.2
mic pos 5	77.1	77.2	77.4	89.4	89.5	89.5
oper.ear	80.5	80.4	80.4	93.1	92.9	93.2
L_p	76.3	76.9	77.1			
bkg check	valid	valid	valid			
L_W	89.3	89.9	90.1			

L_{Aeq} bkg	19	dB(A)
$L_{Aeq\ tool}$	76.8	dB(A)
$L_{Aeq\ operator\ ear}$	**80.4**	dB(A)
$L_{Cpk(max)}$	**93.2**	dB(C)
L_{WA}	**90**	dB(A)



10 APPENDIX C – L_{PA} AT OPERATOR’S EAR: DETAIL

Site #1

Tool	OP#1 dB(A)	OP#2 dB(A)	OP#3 dB(A)	OP#5 dB(A)	OP#6 dB(A)	L_{Aeq} op ear dB(A)	L_{Aeq} bkg dB(A)	exceeds bkg by dB(A)	notes
A	87.8	85.6	86.7	-	-	86.8	80.5	6.3	
B	87.3	87.3	86.9	-	-	87.2	80.5	6.7	
C	88.2	86.5	86.9	-	-	87.3	80.5	6.8	
D	84.2	83.9	82.4	-	-	83.6	80.5	3.1	
E	85.0	87.2	84.3	-	-	85.7	80.5	5.2	silenced exhaust
F	83.4	80.5	83.7	-	-	82.8	80.5	2.3	silenced exhaust
G	94.6	97.0	85.3	-	-	94.4	80.3	14.1	
H	85.2	87.3	89.9	-	-	87.9	80.3	7.6	
I	85.9	87.2	87.1	-	-	86.8	80.5	6.3	
J	-	-	-	86.0	86.3	86.2	75.4	10.8	
K	-	-	-	92.9	90.2	91.8	75.4	16.4	
L	-	-	-	91.5	89.3	90.5	75.4	15.1	without sleeve
M	85.4	84.7	85.4	-	-	85.2	80.3	4.9	

Site #2

Tool	OP#1 dB(A)	OP#2 dB(A)	OP#3 dB(A)	OP#1b dB(A)	OP#2b dB(A)	L_{Aeq} op ear dB(A)	L_{Aeq} bkg dB(A)	exceeds bkg by dB(A)	notes
A			86.5	85.8	84.4	85.7	67.2	18.5	
B		89.3	89.9			89.6	75.2	14.4	
C	91.1	88.2	89.3			89.7	75.2	14.5	not connected to vac
D	84.1	81.9	84.0			83.4	75.2	8.2	close to carriage
E	84.7	82.6	83.8			83.8	67.2	16.6	bkg lower - no spray booth & no extraction
F	86.7	85.6	85.5			86.0	67.2	18.8	
G						0.0		0.0	
H						0.0		0.0	
I			88.0	89.7	86.3	88.2	81	7.2	bkg with extract on
J						0.0		0.0	
K						0.0		0.0	
L						0.0		0.0	
M						0.0		0.0	

Site #3

Tool	OP#1 dB(A)	OP#2 dB(A)	OP#3 dB(A)	OP#1b dB(A)	OP#2b dB(A)	L_{Aeq} op ear dB(A)	L_{Aeq} bkg dB(A)	exceeds bkg by dB(A)	notes
A						0.0		0.0	
B						0.0		0.0	
C						0.0		0.0	
D						0.0		0.0	
E						0.0		0.0	
F						0.0		0.0	
G	101.4	99.8				98.9	40.3	58.6	180 grit
H	89.7	87.5				87.0	40.3	46.7	240 grit (no holes)
I						0.0		0.0	
J						0.0		0.0	
K						0.0		0.0	
L						0.0		0.0	
M	88.6	88.1				86.6	40.3	46.3	320 grit

Site #4

Tool	OP#1 dB(A)	OP#2 dB(A)	OP#3 dB(A)	OP#1b dB(A)	OP#2b dB(A)	L_{Aeq} op ear dB(A)	L_{Aeq} bkg dB(A)	exceeds bkg by dB(A)	notes
A	85.1	86.2	84.1			85.2	74.6	10.6	320 vac (running slow)
B	88.9	90.5	87.2			89.1	74.6	14.5	320 silenced
C	90.0	89.7	86.7			89.0	74.6	14.4	320 silenced & vac
D	86.3	83.9	79.3			84.0	74.6	9.4	320 silenced
E	80.4	84.0	81.9			82.4	74.6	7.8	320 silenced
F	82.7	82.6	81.2			82.2	74.6	7.6	180 silenced
G						0.0		0.0	
H						0.0		0.0	
I	85.3	86.0	84.9			85.4	74.6	10.8	400 silenced
J	88.5	84.4	81.3			85.7	74.6	11.1	
K						0.0		0.0	our foam pad - not really suitable for task
L	83.1	82.4	82.3			82.6	74.6	8.0	lambswool bonnet
M						0.0		0.0	

Site #5

Tool	OP#1 dB(A)	OP#2 dB(A)	OP#3 dB(A)	L_{Aeq} op ear dB(A)	L_{Aeq} bkg dB(A)	exceeds bkg by dB(A)	notes
A	95.3	93.7	92.7	94.0	72.6	21.4	OP1 & 2 @ 80 grit. OP3 @ 320 grit.
B	90.6	88.0	88.3	89.1	72.6	16.5	OP1 & 2 @ 120 grit. OP3 @ 320 grit.
C	88.7	91.3	90.5	90.3	72.6	17.7	OP1 & 2 @ 120 grit. OP3 @ 320 grit.
D	85.4	83.6	82.0	83.9	72.6	11.3	OP1 & 2 @ 80 grit. OP3 @ 320 grit.
E.1	94.1	94.9	97.3	95.7	72.6	23.1	OP1 & 2 @ 120 grit. OP3 @ 320 grit. Hose & bag!!!
E.2							
F.1	87.5	85.0	87.3	86.7	72.6	14.1	All OP's @ 180 grit. Hose & bag!!!
F.2							
G							
H							
I	88.2	87.0	86.7	87.3	72.6	14.7	OP1 & 2 @ 80 grit. OP3 @ 180 grit.
J	83.9	83.1	82.8	83.3	74	9.3	Our pad. Their liquid.
K	93.5	86.0	90.1	90.9	74	16.9	Our pad. Their liquid.
L.1							
L.2	78.3	76.3	76.6	77.2	74	3.2	New compounding pad with G3 advanced liquid compound.
M							

11 APPENDIX D – EQUIPMENT

Equipment	Serial number
B&K 2260 Investigator	2305154
B&K 4189 microphone	2294166
B&K 4231 acoustic calibrator	2309005
B&K Pulse 3032A 6/1 – Ch input/output module	2325758
DELL Latitude laptop (Pulse 2001)	99123
B&K 4134 microphone 1	1625411
B&K 4134 microphone 2	1625402
B&K 4134 microphone 3	929525
B&K 4134 microphone 4	982377
B&K 4134 microphone 5	736121
B&K 2619 preamplifier 1	608001
B&K 2619 preamplifier 2	418630
B&K 2619 preamplifier 3	608004
B&K 2169 preamplifier 4	990257
B&K 2169 preamplifier 5	990252
B&K 2804 power supply	684344
B&K 2804 power supply	761775
B&K 2804 power supply	684342

12 REFERENCES

[1] Control of Noise at Work Regulations 2005
Statutory Instrument 2005 No. 1643

[2] EU Physical Agents (Noise) Directive (2003/10/EC)

[3] The Supply of Machinery (Safety) Regulations 1992 (as amended)
Statutory Instrument 1992 No. 3073

[4] BS EN ISO 3744:1995
Acoustics. Determination of sound power levels of noise sources using sound pressure. Engineering method in an essentially free field over a reflecting plane.
(confirmed, current)

[5] BS EN ISO 15744:2002
Hand-held non-electric power tools. Noise measurement code. Engineering method (grade 2)
(current)

[6] BS EN ISO 11203:1996
Acoustics. Noise emitted by machinery and equipment. Determination of emission sound pressure levels at a work station and at other specified positions from the sound power level
(confirmed, current)

[7] BS EN 50144-1:1996
Safety of hand-held electric motor operated tools. Part 1: General requirements
(current, revised, work in hand)

[8] BS EN 50144-2-3:2002
Safety of hand-held electric motor operated tools. Part 2-3: Particular requirements for grinders, disk type sanders and polishers
(current)

[9] BS EN 50144-2-4:2000
Safety of hand-held electric motor operated tools. Part 2-4: Particular requirements for sanders
(superseded, withdrawn)

[10] BS EN 60745-1:2003
Hand-held motor-operated electric tools. Safety. Part 1: General requirements
(current, work in hand)

[11] BS EN 60745-2-4:2003
Hand-held motor-operated electric tools. Safety. Part 2-4: Particular requirements for sanders and polishers other than disk type
(current, work in hand)

[12] BS EN ISO 11202:1996
Acoustics. Noise emitted by machinery and equipment. Measurement of emission sound pressure levels at a workstation or other specified positions. Survey method in situ
(confirmed, current)

[13] BS EN ISO 3746:1996
Acoustics. Determination of sound power levels of noise sources using sound pressure. Survey method using an enveloping measurement surface over a reflecting plane (confirmed, current, work in hand)

[14] PN8NTC1.2
Noise test code for measurement of noise from hand-held non-electric power tools 14.00 Pneurop

[15] BS EN 792-8:2001
Hand-held non-electric power tools. Safety requirements. Part 8: Sanders and polishers

[16] BS EN ISO 4871:1997
Acoustics. Declaration and verification of noise emission values of machinery and equipment

[17] NV/06/18
Correlation between vibration emission and vibration during real use - Polishers and sanders