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MEASUREMENT UNCERTAINTIES IN THE SOUND POWER PROCEDURES BASED ON SOUND INTENSITY

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Abstract

Sound power determinations were carried out on two different hydraulic fluid power pumps according to ISO 9614 part 2 Standard. Each pump was mounted on a specific hydraulic circuit under controlled conditions of installation and operation and three different scanning paths were selected on the measurement surface in order to have different scan line densities on each partial surface. After an initial warm-up period, a dataset of ten consecutive sound power determinations were carried out while each pump was running in fixed continuous mode. For each scanning configuration, the repeatability uncertainty values were obtained by measuring the variation of the sound power levels over the time. These results were compared with the accuracy values determined according to the sound field indicator criteria specified in the Standard.

INTRODUCTION

In recent years, a large number of European Directives have been published containing requirements for sound power determinations and the noise labelling has become mandatory for most equipment and machines. In this context, the knowledge of the uncertainties accompanying the results has become essential for many purposes, either when the conformity with a specification or a limit value has to be tested, or when values have to be simply compared to each others.

In the existing standards for determining sound power levels, the aspect of uncertainties is presently handled in different ways but a review of these Standards is in progress, aiming at harmonising all the current methods, according to the GUM document.

Referring to the international standards for sound power determination based on sound intensity, it is a very hard task to evaluate the measurement uncertainties as specified in GUM document, primarily due to the fact that measurements take place under widely different conditions [1]. On the other hand, the three ISO standards specify only estimated upper values for the standard deviation of reproducibility whose values have to be checked time by time by evaluating specific field indicators.

This paper aims at investigating more in detail the influences of source operating conditions and sound intensity sampling over the measurement surface on the uncertainty values associated to the sound power results.

EXPERIMENTAL APPROACH

The investigations involved two different gear pumps with the same number of teeth but different displacement volumes. These components were mounted on a specific test rig where the oil temperature and the working pressure values could be constantly monitored by suitable gauges. A concrete wall was built between the tested pump and the rig in order to have a reflecting plane at the mounting face with the inlet and outlet pipes passing throughout it [2]. Table 1 summarises the characteristics of the tested sources and their operating conditions during tests.

Table 1 – Noise sources and their operating conditions during tests

	Pump A	**Pump B**
Dimensions (m)	0.08x0.09x0.11	0.07x0.10x0.09
Group	2	1
Tooth Number	12	12
Displacement volume cm^3/rev	4.0	9.8
Working Pressure (bar)	80	80
Rotational Speed (rev/min)	1480	1480

Measurements were performed in a large shed, in presence of stationary background noise, using a B&K Pulse analyser equipped with a monoaxial sound intensity probe with ½” microphones and a 12 mm spacer.

All the acquisitions were carried out over the same surface, a 0.64x0.36x0.62 m^3 parallelepiped including both the inlet and outlet pump pipes and centred with to the tested source. Three different scanning path configurations were defined on the measurement surface (6x3x5, 8x4x8,10x6x10) and a manual scan was performed twice on each partial surface with a scanning speed as constant as possible. On partial surfaces where the scanning path was too short for the fulfilment of the Standard requirements (scanning time greater than 20 s and speed ranging from 0.1 to 0.5 m/s), the scan on the selected path was repeated more times until the fulfilment was reached. The details on the three configurations are summarized in Table 2.

Table 2 – Measurement configurations

	6x3x5		**8x4x8**		**10x6x10**	
	N. Lines		***N. Lines***		***N. Lines***	
Elements	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
Frontal side	5	6	8	8	10	10
Lateral sides	5	3	8	4	10	6
Top/bottom sides.	3	6	4	8	6	10

For each pump and configuration, a dataset of ten consecutive sound power determinations according to the ISO 9614-2 procedure was carried out after an initial warm-up period for the pump aimed at increasing the temperature of the oil in the hydraulic circuit until the minimum value recommended by the manufacturer (30±1 °C) was reached. The time necessary to perform the ten consecutive tests mainly depended on the scanning path: 100 minutes for the 6x3x5 configuration, 150 minutes for the 8x4x8 and 200 minutes for the 10x6x10. During this period, the operating conditions of the sources kept constant while the oil temperature in the circuit increased. The amount of this increase was different for the two pumps and significantly more marked for the pump with the highest displacement volume (pump B).

RESULTS AND DISCUSSION

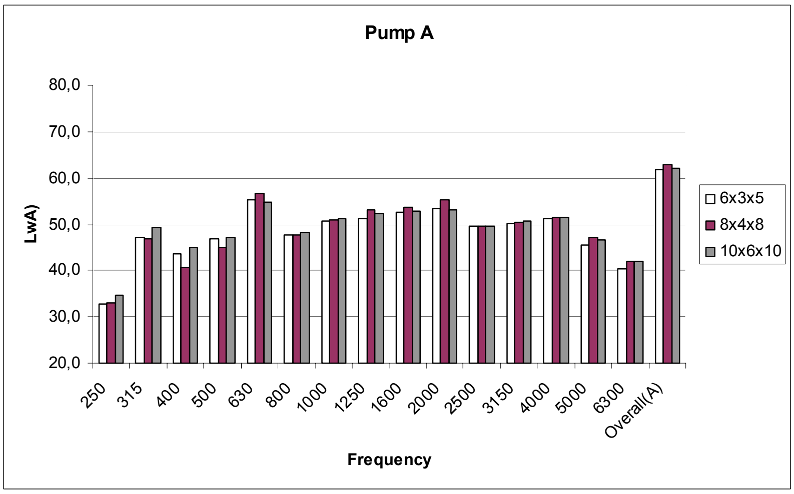
For each pump, the measurement accuracy of the sound power results was examined according to two different approaches. Firstly, a measure of the spread of the sound power levels over the several repeated sound power tests were obtained for each path configuration (6x3x5, 8x4x8,10x6x10). Then for the same groups of sound power results the grade of accuracy was determined according to the sound field indicator criteria given in the ISO 9614-2 Standard.

The analysis of the repeated results obtained for pump B showed that after the start-up this source emitted considerably high noise components, specially in the medium-high frequency range and these noise components suddenly decreased as soon as the oil temperature in the circuit reached 40°C at least. For this reason this initial period was considered not characterising the typical noise emission of this hydraulic component and all the sound power results obtained at temperatures lower than 40 °C were excluded from the analysis. In consequence of this exclusion, the data set for this pump finally included seven repeated measurements for the 8x4x8 scanning path and eight repeated measurements for the 6x3x5 and 10x6x10 configurations, respectively. For pump A no significant changes in the noise emission related to the oil temperature were observed and all the thirty repeated sound power results were considered for analysis.

Repeatability standard deviations

The repeatability uncertainty was assessed in terms of standard deviation by describing how the different individual sound power spectra deviated from the average.

For each pump, figure 1 shows the A-weighted average sound power spectrum obtained for each scanning path configuration (6x3x5, 8x4x8,10x6x10) from the different datasets of consecutive measurements. Table 3 gives a summary of the standard deviation values for each one-third octave band in the 315-6300 Hz frequency range.



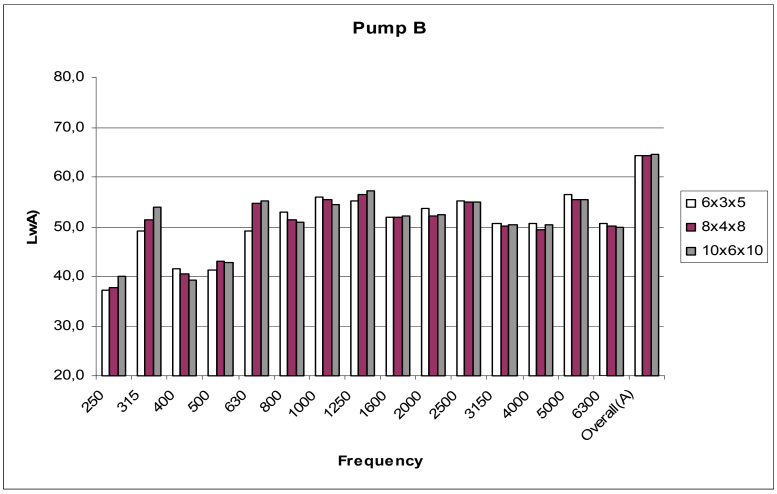


Figure 1 – A-weighted sound power mean spectra for each configuration and pump

It may be seen that the standard deviation values associated to the overall A-weighted levels are always lower than 0.35 dB; only the value obtained for pump B from the set of measurements carried out with the 6x3x5 configuration reaches 0.57 dB.

Table 3 – Spread of the sound power levels for each group of repeated measurements in terms of standard deviation values

		315	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	Overall
Pump A	6x3x5	1,73	0,69	0,6	0,63	0,40	0,82	0,49	0,36	0,14	0,24	0,18	1,20	0,31
	8x4x8	0,83	0,96	0,4	0,32	0,38	0,32	0,46	0,39	0,29	0,51	0,84	1,20	0,27
	10x6x10	4,41	0,60	0,5	0,74	0,46	0,37	0,45	0,29	0,17	0,17	0,93	1,50	0,29
Pump B	6x3x5	0,55	2,29	0,78	0,84	0,46	2,00	0,72	0,95	1,26	0,69	1,46	1,46	0,57
	8x4x8	0,67	0,53	0,51	0,68	0,49	0,94	0,56	0,22	0,59	0,23	1,20	1,20	0,20
	10x6x10	0,65	0,85	0,66	1,31	0,43	0,98	0,38	0,51	1,27	0,32	1,09	1,09	0,23

The repeatability values in the one-third octave bands are generally higher than the values associated to the overall level but normally they are lower than 1.5 dB. The extremely high value obtained for pump A from the set of measurements carried out with the 10x6x10 configuration (315 Hz) is not critical as it refers to a noise component not much significant having a power level considerably lower than the overall one. The very high values obtained for pump B from the set of measurements carried out with the coarse configuration (630 Hz and 1600 Hz), on the contrary, are important but they are strictly related to the fact that the set of results included one test carried out just during the transition phase between the initial period with significantly high noise levels and the stabilization period with stationary and lower noise emission.

On the whole, the standard deviation values are consistent and even significantly lower than the reproducibility standard deviations specified for engineering precision grade measurements in the 9614-2 Standard.

Finally, the comparison of the uncertainty values obtained for the three different scanning paths doesn't show any significant advantage of the finer configurations on the spreading of the sound power results.

Sound field indicator criteria

For each pump and each set of sound power results, the accuracy was determined by evaluating the sound field indicators specified in ISO 9614-2 and by checking the fulfillment of the three criteria defined in this standard.

All the sets of sound power results fulfilled the criterion concerning the evaluation of instrument capability (criterion 1: $F_{pI} < L_d$) and that of negative partial power (criterion 2: $F_{+/-} \leq 3$ dB).

On the contrary, the fulfillment of criterion 3 (partial power repeatability check) turned out to be extremely difficult. However, this Standard provides for additional tests in order to limit the accuracy considerations only to the frequency bands and the partial sound power contributions which really give a significant contribution to the sound power emission of the source. By applying these procedures, the fulfillment of criterion 3 was achieved not only for the overall sound power values but also for a high percentage of band levels. Table 4 shows the results for pump A and pump B.

Table 4 –Exclusion of the insignificant bands and fulfillment of criterion 3

			315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300
Pump A	6x3x5	Nr.tests with significant bands	3/10	5/10	5/10	10/10	7/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10
		Nr.tests where criterion is fulfilled	2	5	5	4	7	7	9	10	10	10	10	10	10	10
	8x4x8	Nr.tests with significant bands	7/10	3/10	6/10	10/10	9/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10
		Nr.tests where criterion is fulfilled	7	3	6	6	9	10	10	10	10	10	10	10	10	10
	10x6x10	Nr.tests with significant bands	6/10	6/10	7/10	10/10	8/10	9/10	10/10	10/10	10/10	10/10	10/10	10/10	9/10	10/10
		Nr.tests where criterion is fulfilled	4	6	6	2	8	7	10	10	10	10	10	10	9	10
Pump B	6x3x5	Nr.tests with significant bands	1/8	1/8	2/8	1/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8
		Nr.tests where criterion is fulfilled	1	1	2	0	8	8	8	8	8	8	8	7	8	8
	8x4x8	Nr.tests with significant bands	5/7	1/7	6/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7	7/7
		Nr.tests where criterion is fulfilled	5	1	6	7	7	7	7	7	7	7	7	7	7	7
	10x6x10	Nr.tests with significant bands	7/8	0	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8
		Nr.tests where criterion is fulfilled	3		8	8	8	8	8	8	8	8	8	8	8	8

The best estimate of the power spectrum characterizing the noise emission of each pump was obtained for each scanning path configuration. In particular, for each one-third octave band in the 250÷6300 Hz frequency range the best estimate ($L_{Wi,ref}$) was assessed as mean value among all the sound power results which turned out to be significant after the application of the additional procedures and fulfilled all the field indicator criteria.

Concerning the scanning configuration 6x3x5, Figure 2 shows the scattering of all sound power results around these best estimated values for each frequency band and for each pump. Figure 3 and Figure 4 show the same graph for the 8x4x8 and 10x6x10 configurations.

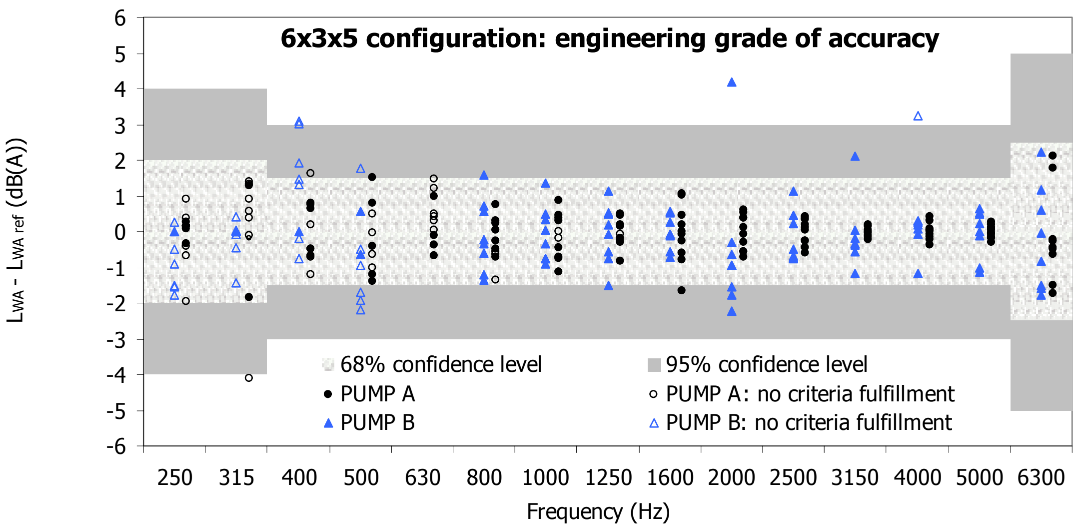


Figure 2 – 6x3x5: scattering of the sound power results around the best estimated values

In order to qualify the spread of the data around the averaged values (best estimates) in terms of standard deviation, two areas were identified with a grey background colour: the narrower one indicating a 68% confidence interval for engineering grade of accuracy and the wider one for a 95% confidence interval. It may be seen that independently on the fulfillment of the partial power repeatability criterion, the percentage of the results included in the intervals ±1s and ±2s for the engineering grade of accuracy is very high. In particular, within the ±1*s* interval are included the following percentages of sound power results:

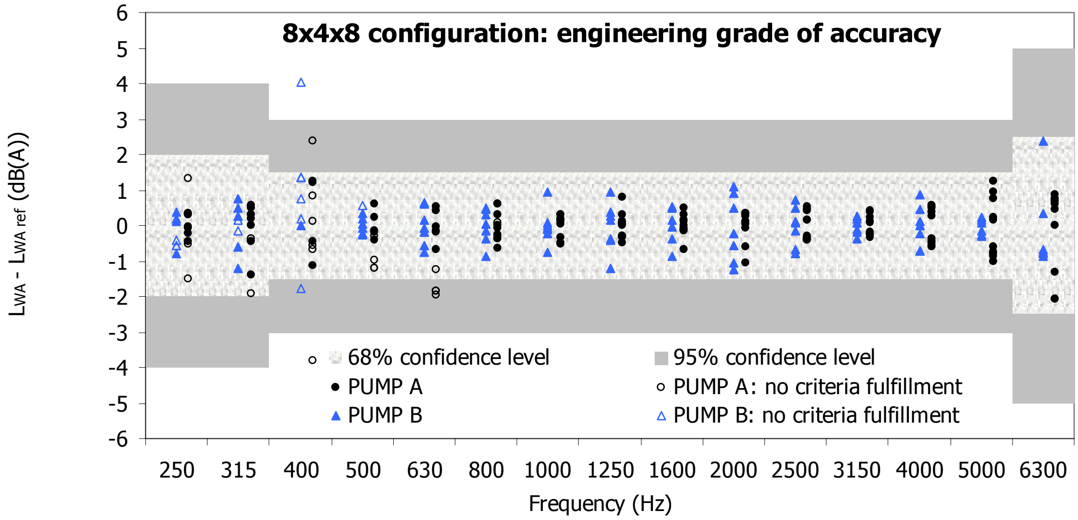


Figure3 – 8x4x8: scattering of the sound power results around the best estimated values

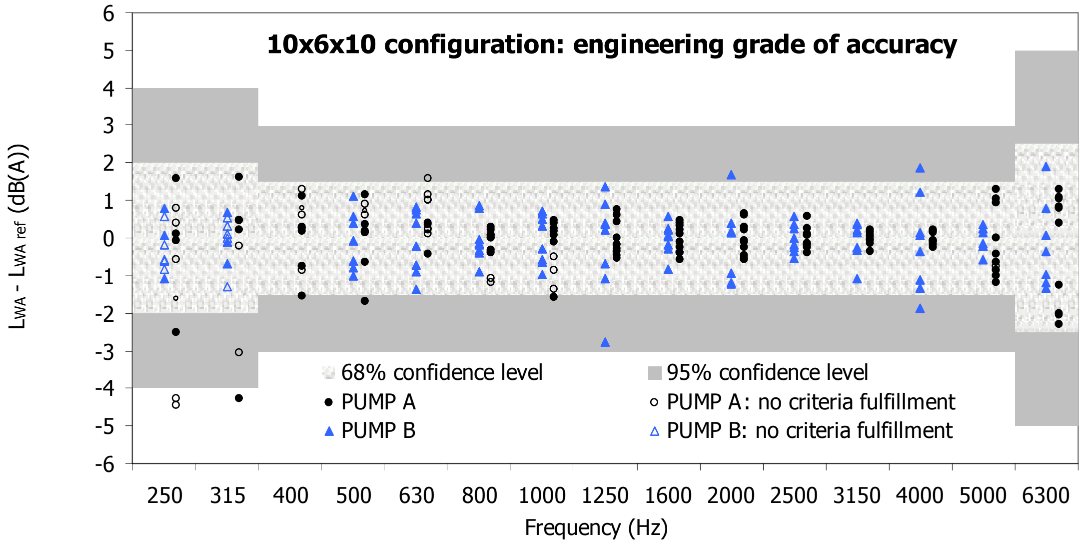


Figure 4 – 10x6x10: scattering of the sound power results around the best estimated values

configuration 6x3x5: pump A: 97.3% - pump B: 81.7%
configuration 8x4x8: pump A: 95.3% - pump B: 97.1%
configuration 10x6x10: pump A: 92.7 % - pump B: 86.7%

and within ±2s interval:

configuration 6x3x5: pump A: 99.0% - pump B: 90.0%
configuration 8x4x8: pump A: 99.3% - pump B: 99.0%
configuration 10x6x10: pump A: 96.7 % - pump B: 91.7%

In addition, as to the overall sound power levels are concerned, the differences between the best estimate according to the accuracy criteria specified in ISO 9614-2 standard and the overall mean level obtained from all the set of repeated measurements (30 for pump A and 23 for pump B) were always less than 0.3 dB.

CONCLUSIONS

The many repeated sound power tests carried out on two different hydraulic pumps by applying the ISO 9614-2 procedure allowed us to investigate in detail the influence of source operating conditions and scanning path configurations on the accuracy of the results. All the sound power levels obtained with the coarse scanning configuration (6x3x5) attained the engineering grade of accuracy as to the overall sound power levels are concerned and as to each band level in the 250-6300 frequency range. The use of finer configurations (8x4x8, 10x6x10) really didn't add any further advantage.

All the sets of sound power results fulfilled the sound field criterion concerning the evaluation of instrument capability and that of negative partial power. On the contrary, the fulfillment of criterion concerning the partial power repeatability (criterion 3) turned out to be extremely difficult. Only by applying the additional procedures specified in this Standard, which are laborious and time consuming, the fulfillment of this criterion was achieved for a high percentage of band levels. On the other hand, for both the sources, the limited differences between the results from the different dataset of consecutive measurements and the best estimates of the sound power spectrum according to the accuracy criteria specified in ISO 9614-2, confirmed the poor effectiveness of this criterion.

Finally, the repeated sound power tests showed the importance to carry out measurements only after that stable sound emission conditions are reached for the tested source, otherwise the uncertainty values increase significantly.

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