



ICPEs 2025

40th INTERNATIONAL CONFERENCE ON PRODUCTION ENGINEERING - SERBIA 2025

DOI: [10.46793/ICPEs25.475D](https://doi.org/10.46793/ICPEs25.475D)



Nis, Serbia, 18 - 19th September 2025

ACCURACY OF SOUND POWER DETERMINATION USING DIFFERENT SOUND INTENSITY METHODS: A CASE STUDY ON A VACUUM PUMP

Tanja DULOVIĆ^{1*}, Branko RADIČEVIĆ¹, Jovana PERIĆ¹, Mladen RASINAC¹,
Vladan GRKOVIĆ¹

Orcid: 0000-0003-3265-5661; Orcid: 0000-0002-4182-4095; Orcid: 0000-0003-4933-3756;
Orcid: 0000-0003-1229-4678;

¹University of Kragujevac, Faculty of Mechanical and Civil Engineering in Kraljevo, Serbia

*Corresponding author: dulovic.t@mfkv.kg.ac.rs

Abstract: This study presents the measurement and analysis of the sound power emitted by a vacuum pump using two sound intensity-based methods in accordance with ISO 9614: the discrete point method and the scanning method. The sound intensity measurements were conducted under two airflow conditions (5 l/min, 15 l/min) in the frequency range from 200 to 6000 Hz range. The results indicate a high level of agreement between the two methods in terms of the frequency distribution of sound power, with the discrete point method yielding slightly higher values due to more detailed spatial sampling. The maximum observed difference between the methods was 2.4 dB, recorded at 250 Hz and 400 Hz. The highest sound power levels occurred between 1000 and 2000 Hz, which corresponds to the typical spectral range of mechanical noise. The result showed that noise emission's loudest source is the rear face of the pump, likely due to the position of the electric motor cooling fan. These findings validate both techniques for use in describing noise emissions from similar equipment.

Keywords: sound power, sound intensity, vacuum pump.

1. INTRODUCTION

Effective noise control strategies are based on a clear understanding of the characteristics of the noise sources. Among these, sound power is considered a reliable parameter for evaluating and comparing different sources, as it is independent of the acoustic environment and allows for consistent definition of acceptable emission limits [1].

Traditional methods for determining sound power are most commonly based on sound pressure level measurements. However, these

approaches often face significant limitations, particularly in terms of measurement accuracy and susceptibility to background noise [2]. In recent years, sound intensity measurement has gained increasing recognition as an alternative technique for estimating sound power, offering several advantages over conventional methods. Sound intensity is a vector quantity that include both the magnitude and direction of sound propagation, allowing for more accurate source localization and reduced influence of environmental conditions on the results [3,4]. This method allows the precise

identification of dominant noise sources and the visualization of spatial sound intensity distribution [5]. Overall, sound intensity measurement provides a practical and cost-effective alternative to traditional sound power determination techniques, eliminating the need for large investments in reverberation or anechoic chambers.

Diaphragm vacuum pumps are commonly used in various laboratory settings, industrial applications, and processes that require stable and controlled vacuum conditions. During operation, these pumps generate significant noise levels due to the characteristic vibrations of the diaphragm, further intensified by friction and interactions between moving components [6]. In addition, the pulsating nature creates pressure variation and turbulence, which directly affect noise emission [7,8]. Operating conditions, such as airflow rate and pump load, also affect significantly the noise dynamics. An increase in speed and load leads to higher noise levels, due to higher vibration effects and higher turbulence [9]. Due to these factors, the characterization and measurement of noise generated by vacuum pumps are of key importance for improving their performance, reliability, and environmental acceptability in the contexts in which they are used.

The research object in this study is the determination of the sound power level of the ZAMBELLI vacuum pump, model ZB1, using the sound intensity measurement method. Due to its compact design, precise flow control, and wide operating range (0.2–30 l/min), the ZAMBELLI ZB1 pump is a common choice for both laboratory and field measurements. In this research, two sound intensity measurement techniques were applied: the discrete point method [10], in accordance with ISO 9614-1, and the scanning method [11], in accordance with ISO 9614-2. The main objective of this work is to analyze and compare the applicability of these methods for accurate determination of the sound power level of the ZB1 pump and to discuss the results in terms of noise reduction and performance optimization.

2. INTENSITY MEASUREMENT METHODS

The most commonly used procedure in sound intensity measurement is based on the use of an intensity probe. This method involves two microphones placed at a small distance apart. Its main advantage involves the determination of sound intensity only in the direction given by the axis between the two microphones, allowing spatial selection of the analyzed sound sources and effectively minimizing the influence of background noise [12].

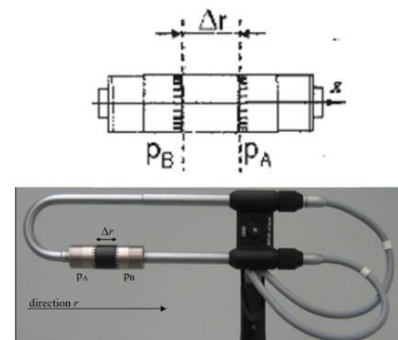


Figure 1. Face to face dual-microphone structure

Sound intensity can be estimated from the ratio of the pressures measured by microphones A and B, separated by a known distance, according to Equation (1):

$$I(t) = \frac{1}{2\rho_0\Delta r} [p_A(t) + p_B(t)] \int [p_A(t) - p_B(t)] dt \quad (1)$$

where $I(t)$ represents the sound intensity estimate in the direction (r) [W/m^2], $p_A(t)$ is the sound pressure in the time domain captured by microphone A [Pa]; $p_B(t)$ is the sound pressure in the time domain captured by microphone B [Pa]; Δr is the separation distance between microphones A and B [mm] and ρ is the volumetric density of the environment [kg/m^3].

The determination of sound power using sound intensity measurements is based on forming a measurement surface around the noise source, with the distance between the source and the probe being limited. Since sound power is proportional to the surface area of the measurement surface (equation (2)), it is used to calculate the power of the source. According to ISO 9614-1 and ISO 9614-2 standards, the minimum distance from the source to the measurement probe ranges from

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----

475

perpendicularly to the surface at a distance of 0.5 m, and data were collected sequentially within the defined grid to capture the full sound radiation of the device.

2.2 Scanning method

The scanning method involves continuous movement of the probe along predefined paths on the measurement surface, resulting in a time–space averaged value of the sound intensity. This approach reduces the overall measurement time and enables faster estimation of total sound power, but it is more sensitive to irregularities in scanning speed and less suitable for sources with localized intensity maxima.

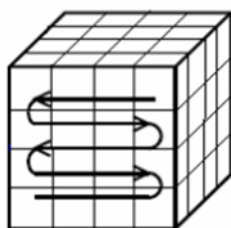


Figure 5. Measurement by scanning method [13]

In accordance with the standard [11], the device surfaces were scanned to capture the noise radiation as comprehensively as possible. A total of five surfaces were analyzed—front, rear, top, left, and right. On each surface, a measurement grid was defined, and the sound intensity was continuously recorded by moving the probe along predefined paths, as illustrated in Figure 6. This approach ensures efficient coverage of the entire sound field and reliable determination of the total sound power of the device [13].

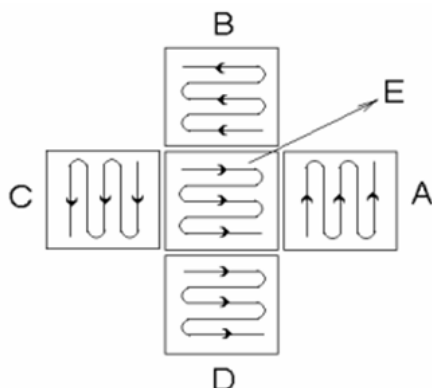


Figure 6. Orientation of sound intensity probe during measurement using the scanning method

The probe scanning speed is determined based on the total distance covered over each partial surface within the selected measurement time, as defined in ISO 9614-2.

3. RESULTS

Numerous studies have confirmed that the technique of determining sound power through sound intensity measurements represents a reliable and flexible alternative to classical methods in reverberant conditions. In the research [13] it was demonstrated that this technique yields results with deviations of less than ± 2 dB compared to the reverberation method, with the additional advantage of identifying noise sources and the possibility of use in uncontrolled environments. Mohsen Aliabadi et al. [1] concluded that the sound intensity method is applicable even in high-background noise conditions, although accuracy may decrease when measuring non-uniformly radiating sources due to uneven sound fields and external noise interference. Similarly, Wittstock et al. [14] showed that despite the presence of background noise, it is possible to achieve high measurement accuracy using this method; however, sources that do not radiate uniformly present a challenge in terms of result reliability.

Based on the conclusions from these studies, this paper presents an analysis of the results obtained using both the discrete point method and the scanning method, with the available equipment at the Faculty of Mechanical and Civil Engineering in Kraljevo. The investigation included measurements of the overall sound power level as a function of frequency, as well as the spatial distribution of sound energy over the surfaces surrounding the noise source. The analysis was conducted under two airflow conditions (5 l/min and 15 l/min) to assess the influence of operating parameters on noise emission.

Measurement results at a frequency of 200 Hz (Figure 7) indicate that the rear surface generated the highest sound power level, with

values of 47.7 dB for an airflow rate of 15 l/min and 49.6 dB for 5 l/min. This indicates dominant noise radiation toward the rear side of the device, which is a direct consequence of the position of the cooling fan for the electric motor that draws in air during operation, thereby generating increased sound radiation in that direction. On the other hand, the lowest sound power levels were observed on the lateral surfaces, suggesting limited propagation of sound energy in those directions due to the pump housing geometry and reduced influence of vibrations.



Figure 7. Distribution of sound power over the measurement surfaces at a frequency of 200 Hz, for two different flow rates (left: 5 l/min, right: 15 l/min), obtained using the discrete points method

The contour maps of sound power on the rear surface of the device, shown in Figure 8, provide a visual representation of the spatial distribution of noise radiation. The most intense radiation zone is localized in the lower central part of the surface, which corresponds to the location of the pump's exhaust outlet.

At a flow rate of 15 l/min, a higher sound power level is observed in this zone—reaching 52 dB, compared to 31 dB at a flow rate of 5 l/min. This indicates an increase in noise emission due to higher dynamic pressure and air turbulence at increased flow, which is consistent with the expected behavior of the fan under such conditions.

The distribution of sound power extends concentrically from the center toward the edges, with a gradual decrease in noise levels, which is characteristic of localized and directional sources such as fans or compressor components. These results further support the findings obtained from the surface-based sound power analysis, emphasizing the significance of the rear surface as the primary noise-radiating segment of the device.

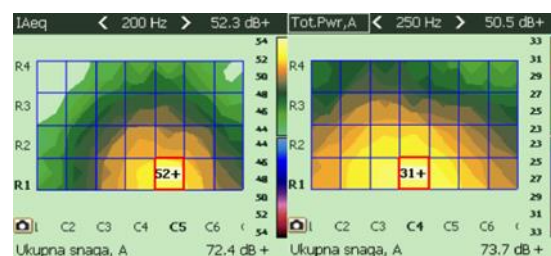


Figure 8. Contour map of sound power on the rear surface of the device – comparison for flow rates of 5 l/min and 15 l/min

A similar trend is observed for both methods – sound power increases with frequency in the low-frequency range, reaches a maximum between 1000 and 2000 Hz, and then gradually decreases toward higher frequencies (Figure 9). This spectrum indicates dominant noise radiation in the mid-frequency range, which is typical for mechanical noise sources such as vacuum pump.

When comparing the results for the two flow rates, it can be noted that, in most frequency bands, the total sound power at the lower flow rate (5 l/min) is slightly higher than at the higher flow rate (15 l/min), especially in the high-frequency range (≥ 4000 Hz). This can be explained by the higher local air velocity at lower flow, due to the narrowed cross-section inside the rotameter, which leads to intensified turbulence and more pronounced noise emission. Similar effects have been reported in previous studies [9], which showed that flow dynamics and diaphragm mechanism stability significantly affect the level of emitted noise.

The discrete point method shows a slightly higher sound power level compared to the scanning method across most frequency bands, which is expected given the more detailed sampling this method involves. On the other hand, both methods display a similar frequency distribution and strong agreement in overall trends, indicating the reliability of the measured values.

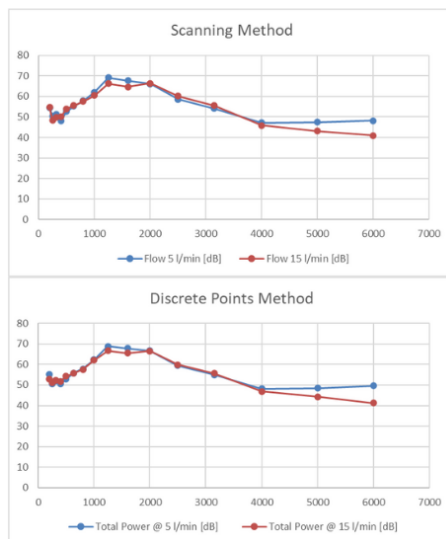


Figure 9. Total sound power measurement results for two flow regimes (5 l/min and 15 l/min), obtained using the scanning method and the discrete point method

4. CONCLUSION

This study analyzed the sound power of a vacuum pump using two sound intensity-based measurement methods – the discrete-point method (ISO 9614-1) and the scanning method (ISO 9614-2). Both methods produced results consistent with the expected frequency spectrum of mechanical noise sources, with a maximum occurring in the 1000 to 2000 Hz range. A comparison of results at different flow rates (5 and 15 l/min) indicated the influence of operating conditions on the intensity of emitted noise, with sound power generally being higher at the lower flow rate.

The discrete point method enabled high measurement precision and a detailed analysis of the spatial distribution of noise, which proved particularly useful in identifying zones of highest emission, such as the rear surface of the pump in this case. However, this method is more time-consuming due to the requirement to position the probe at a large number of individual points.

The scanning method proved more efficient in terms of measurement duration and ease of use. When properly executed and field-controlled, the results were comparable to those of the discrete-point method, as confirmed by the good agreement in overall

sound power across frequencies. Still, the method shows increased sensitivity to background noise and requires skilled equipment handling.

Taking all aspects into account – accuracy, applicability, measurement duration, and processing complexity – it can be concluded that the choice of method depends on the specific measurement requirements. When detailed emission analysis and source localization are needed, the discrete-point method is preferable. Conversely, in situations where efficiency and simplicity are priorities, the scanning method offers a more practical solution. Both approaches, when properly implemented, provide results that comply with ISO 9614 and are sufficiently reliable for practical application.

ACKNOWLEDGEMENT

The authors acknowledge the support of Ministry of Science, Technological Development and Innovation of Republic of Serbia (contract no. 451-03-136/2025-03/200108). This research contributes to the United Nations 2030 Agenda for Sustainable Development, specifically to Sustainable Development Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

REFERENCES

- [1] M. Aliabadi, R. Golmohammadi, A. Ohad: Empirical Comparison of the In Situ Methods for Determining Sound Power of Typical Embroidery Machine Located in Industrial Workroom, *International Journal of Occupational Hygiene*, Vol. 5, No. 3, pp. 89-95, 2013.
- [2] W. Mickiewicz, M. Raczynski, A. Parus: Performance Analysis of Cost-Effective Miniature Microphone Sound Intensity 2D Probe, *Physical Sensors*, Vol. 20, No. 1, p. 271, 2020.

- [3] N. Knežević, M. Bjelić, K. Jovanović: Performance Analysis of Cost-Effective Miniature Microphone Sound Intensity 2D Probe, *International Journal of Electrical Engineering and Computing*, Vol. 2, No. 1, pp. 20-28, 2019.
- [4] R. Girgis, K. Garner, M. Bernesjö, J. Anger, D. Chu: Measuring no - load and load noise of power transformers using the Sound Pressure and Sound Intensity methods — Part - I: Outdoors measurements, in: *2008 IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century*, 2008, Pittsburgh, PA, USA, pp. 1-8.
- [5] S. Nagata, F. Kenji, T. Wada, D. Asano, T. Yanagisawa: A three-dimensional sound intensity measurement system for sound source identification and sound power determination by In models, *The Journal of the Acoustical Society of America*, Vol. 118, No. 6, pp. 3691-3705, 2005.
- [6] K. Zhao, Y. Lou, G. Peng, C. Liu, H. Chang: A Review of the Development and Research Status of Symmetrical Diaphragm Pumps, *Symmetry in Micro/Nanofluid and Fluid Flow*, Vol. 15, No. 1, p. 2091, 2023.
- [7] Y. Liang, Z. Chen, J. Liao: Numerical simulation and experimental evaluation of flow ripple characteristics of Truninger pump, *Scientific Reports*, Vol. 12, No. 1, 2022.
- [8] Q. Si, C. Shen, X. He, H. Li, K. Huang, J. Yuan, Numerical and experimental study on the flow-induced noise characteristics of high-speed centrifugal pumps, *Applied Sciences*, Vol. 10, No. 9, p.3105, 2020.
- [9] M. Ibrahim, M. Mahat, CFD Analysis of Electromagnetic Based Valveless Pump, *Procedia Engineering*, Vol. 41, pp. 1524-1532, 2012.
- [10] ISO 9614-1, Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 1: Measurement at discrete points, 1993
- [11] ISO 9614-2, Acoustics — Determination of sound power levels of noise sources using sound intensity, Part 2: Measurement by scanning, 1996
- [12] M. Bjelić, N. Knezević, K. Jovanović: Automatizovano merenje intenziteta zvuka pomoću robota i intenzitetske sonde, in: *Proceedings of the 17th International Symposium INFOTEH*, 21-23 March 2018, Jahorina, BiH, pp. 17-22.
- [13] C. M. de Souza, L. C. S. Góes: SOUND POWER DETERMINATION USING ACOUSTIC INTENSIMETRY, APPLYING DISCRETE POINTS AND SCANNING METHODS, in: *Proceedings of COBEM 2007*, 5-9 November 2007, Brasília, DF
- [14] V. Wittstock, S. Brezas, F. Heisterkamp: Sound power determination by intensity—are field indicators and criteria in iso 9614 meaningful?, *The Journal of the Acoustical Society of America*, Vol. 155, No. 1, pp. 588-599, 2024.